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Elizabeth Hunter

# THE
# Young GENTLEMAN and LADY's
# ASTRONOMY,

E.H. FAMILIARLY EXPLAINED 5. 8/6

IN TEN DIALOGUES

BETWEEN

NEANDER and EUDOSIA:

To which is added,

The DESCRIPTION and USE of the

GLOBES and ARMILLARY SPHERE.

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By JAMES FERGUSON, F.R.S.

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*The works of the* LORD *are Great, ſought out of all them that have pleaſure therein* Pſal. CXI. v. 2.

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# ADVERTISEMENT.

THE deſign of the following Treatiſe is to ſhew, that Young Gentlemen and Ladies may acquire a competent knowledge of Aſtronomy, without any previous knowledge of Geometry or Mathematics. How far the Author has ſucceeded in this, is left to the judgment and deciſion of his impartial Readers; to whom, if his labours be agreeable and inſtructive, the purpoſe for which he wrote will be fully anſwered.

which ſhone forth with the greateſt luſtre in the whole of your deportment.—I am ſtill the ſame as before, excepting the improvement I have made at that famous univerſity; where, not only the ſublime ſciences are taught by the greateſt maſters, but the truths of the Chriſtian religion proved in the lectures which I have conſtantly attended.—You know that you and I uſed to converſe familiarly before I went thither: let us do ſo ſtill.

*E.* Dear brother, I cannot expreſs how much you oblige me by this behaviour.—I was afraid before to tell you my mind; but now I will, eſpecially as you are to be here for ſome conſiderable time before you ſet out upon your travels. What I want to learn of you cannot be done, I believe, without taking up a great deal of your time; and perhaps you may think me too vain, in wanting to know what the bulk of mankind think our ſex have no buſineſs with.

*N.* Pray *Eudoſia*, what is that?

*E.* It is nothing leſs than to be in ſome meaſure acquainted with the ſublime ſcience of Aſtronomy; for I have been told, that, of all others, it is the beſt for enlarging our minds, and filling them with the moſt noble ideas of the GREAT CREATOR and his works; and conſequently of drawing us nearer to Him, with an humble ſenſe of our own meanneſs, and of every thing that the greateſt art of man can perform.

*N.* Indeed, ſiſter, whoever told you ſo, told you a great truth; and I am very glad to find you have an inclination to learn the moſt ſublime ſcience that ever was taught by mankind.

*E.* But ſhall I not be laughed at for attempting to learn what men ſay is fit only for *men* to know?

*N.* Never, by any man who thinks right; and I hope you are above minding what thoſe ſay who think wrong.

*E.* Now, let me ſpeak freely.—I have been told, aſtronomers pretend that the ſun ſtands ſtill, and that the earth turns round.—What do you ſay to this?—I know you honour the Bible, and it aſſerts the contrary. Now, I ſee ſo many things in that Book which appear to me to be above all the powers of human compoſition, and carry ſuch evident marks of Divinity with them, as are ſufficient to convince me that they could proceed from none but God: and therefore, I had much rather baulk all my inclinations to learning, than learn any thing that would prejudice my mind againſt the Bible.

*N.* Dear ſiſter, I admire the goodneſs of your heart.—You may depend upon it, that the ſtudy of aſtronomy will never have the leaſt tendency towards prejudicing your mind againſt the Scriptures.—You know that we cannot take every thing there in the ſtrict literal ſenſe. If we did, we ſhould believe that Our Saviour was actually a vine at one time, a door at another, and at a third time a lamb. The Scriptures were given us, to teach us what we ſhould believe, and how we ſhould behave, in order to attain and ſecure to ourſelves the favour of our Maker here, and our perpetual felicity hereafter; which are things infinitely more intereſting to us than all other knowledge and wealth in the world.—They ſpeak according to the common apprehenſions of mankind, in thoſe points which are merely ſpeculative, and have no direct tendency to influence our morals; and, as they never were intended to inſtruct us in experimental philoſophy, or aſtronomy, or in any thing elſe that we could acquire by our own induſtry without them, nothing that regards theſe ſciences can rather be deduced or inferred from them.—One might with as good reaſon take up a law-book and expect to find a ſyſtem of geography in it, as take up the Bible with a view to find a ſyſtem of aſtronomy therein.

*E.* What you have ſaid is rational and juſt; and now, if you pleaſe, I ſhould be glad to enter upon our intended ſubject.—If the ſun does not move, pray, to what is he fixed? and what hinders him from falling down to the earth, when he is ſo high above it, eſpecially at noon in ſummer?

*N.* *High* and *low* are only relative terms; for, when the ſun is at his loweſt depreſſion with reſpect to us, he is directly over-head to ſome other part of the earth; for the earth is round like a globe, and on whatever part of its ſurface a perſon ſtands upright, he thinks himſelf to be on the uppermoſt ſide; and wonders how any one can ſtand directly oppoſite to him, on the undermoſt ſide of the earth; or rather, how he can hang to it, with his head downward, and not fall off to the lower ſky.

*E.* That is what I have often wondered at, when I have heard it affirmed that the earth is habitable on all ſides; or that, where towns cannot be built, ſhips may ſail. How comes it to paſs, that the weight of a ſhip cauſeth it not to fall off from the lower ſeas; or that theſe ſhips and ſeas do not fall off to the lower ſky altogether?

*N.* What we call *weight* is cauſed by *attraction.*—The earth attracts all bodies on or near its ſurface, towards its center, equally on all ſides, every particle of matter alike; and therefore thoſe bodies which contain the greateſt number of particles of matter, acquire from this attraction the greateſt and moſt forcible preſſure; and conſequently have (what we call) the greateſt weight.—The earth may be compared to a great round loadſtone rolled in filings of iron, which it attracts equally on all ſides; ſo that they cannot fall off even from its undermoſt ſide: nay, it will take them up from a table, if they be within the ſphere of its attraction.—

By and by, you ſhall be ſatisfied with reſpect to your query about the ſun.

*E.* So far I underſtand you very well; but ſtill it ſeems odd to me that people ſhould ſtand oppoſite to us on the earth, with their heads downward.

*N.* I believe it does; but you know, that either the ſun muſt go round the earth to give us days and nights, or the earth muſt turn round like a globe on its axis to do ſo: and will not either of theſe motions anſwer the intended purpoſe?

*E.* Undoubtedly it will.

*N.* Now, as I have no mind to deceive you, and ſhall in due time prove every thing that I advance, even to your own ſatisfaction; I do ſay, that the ſun does not move round the earth every twenty-four hours, but that the earth turns round in twenty-four hours: and as the ſun can only enlighten one half the earth at any given inſtant of time, and the other half muſt then be in the dark; this motion of the earth will cauſe the different places on its ſurface to revolve through the light and the dark in twenty-four hours; in which time, of courſe, they muſt have a day and a night: and at the inſtant when it is mid-day at one place, it muſt be mid-night at the oppoſite.—Do you believe what I ſay with reſpect to the earth's turning round?

*E.* I do, becauſe I am fully ſatisfied that you would not knowingly deceive me; and you have promiſed to prove that it does.

*N.* Then, be pleaſed to ſtand up for a minute.—It is now ſeven o'clock in the morning, and you think you are ſtanding upright, on the uppermoſt ſide of the earth.—You will think the ſame if you ſtand upright at ſeven o'clock in the evening, when the earth has turned half round, becauſe you will then perceive no difference of poſture: and yet, at that time, you will be very nearly in the ſame poſition as a perſon is juſt now, who ſtands on the ſide of the earth oppoſite to us: which perſon being as ſtrongly attracted by the earth there, towards its center, as we are here, he is in no more danger of falling off downward, than we are at preſent of falling upward.

*E.* Pardon me, ſir, if you had not been at the univerſity, I ſhould have thought *falling upward* a very improper expreſſion.

*N.* So it is; and I do aſſure you that I never heard ſuch an expreſſion at the univerſity, nor do I remember ever to have uſed it before.—But, to proceed.

*Up* and *down* are only relative terms. Let us be on what part of the earth we will, we call it *up* toward the ſky over our heads; and *down* toward the center of the earth, to which all terreſtrial bodies would fall, by the power of the earth's attraction. So that, with regard to open ſpace, what is *up* from any given point of the earth's ſurface, is *down* from the oppoſite point thereof. And as the ſky ſurrounds the whole earth, we call it *up* toward the ſky over our heads, be where we will; and *down* from our place toward the center of the earth.

*E.* Then, to be ſure, we can perceive no difference, as to our poſition at different times of the day. You have quite ſatisfied me in this: but, pray, how can the earth move, and we not feel its motion?

*N.* I heard you was at Plymouth laſt year; had you not then the curioſity to go aboard ſome of the ſhips there, or at the Dock?

*E.* My papa and I went to the Dock, with a ſmall party of gentlemen and ladies. Mr. *Falconer*, who was then maſter of the Belleiſle happened to be on ſhore; and obſerving that we were ſtrangers, he moſt politely invited us to ſee his ſhip, which was then lying with many others in the Hamoaze. We moſt willingly accepted his invitation, and he took us all out in his boat; ſhewed us firſt into the cabin of the ſhip, and, as it was in the afternoon, he genteely treated the gentlemen with wine, and the ladies with tea; after which, he ſhewed us the whole inſide of his ſhip of war. The way that the different apartments are laid out, eſpecially the powder-magazine, and how it is ſecured from being dangerous; the method of ſteering the helm, and many other things which I cannot well remember, was a ſight not only highly entertaining, but greatly ſurpriſing; and I could not help wondering how it was poſſible for the art of man to contrive and build ſuch a wonderous huge machine, and how it could be managed and conducted through the pathleſs ſeas.

*N.* It is ſurpriſing indeed! but how infinitely more ſo is the power and ſkill of the Great Creator of the univerſe, who has made ſuch prodigious bodies as the planets of our ſyſtem are (one of which is a thouſand times as big as our earth) and has ſet them off in the trackleſs ſpace around us, with ſuch degrees of ſwiftneſs as you will be amazed to hear of; and yet, at the end of each circuit they begin the ſame over again, at the ſame parts of ſpace from which he ſet them off at firſt. —And the diſpoſition of all the apartments of the ſhip will not bear to be compared, not only with the ſtructure of the human body, but even with that of the meaneſt animal on earth.—Was the day calm or windy?

*E.* Scarce a breath of wind was ſtirring: the ſun ſhone clear, which made the ſurface of the water around us have a very pleaſing aſpect: and the ſight of the ſhips about us, and of the town, was a moſt beautiful proſpect.

*N.* I ſuppoſe you looked out through the cabin windows whilſt you were at tea.—Did you ſee the ſame objects all the while?

*E.* I looked out very often; the firſt object I ſaw was a large houſe in the Dock-town; but it ſeemed to me as if it moved very ſlowly toward the right-hand. I ſoon loſt ſight of it, and other objects appeared to my view, and diſappeared ſlowly and gradually; which could ariſe from no other cauſe than the very ſlow and gentle turning of the ſhip the contrary way.

*N.* True: but did you feel the motion of the ſhip?

*E.* Not in the leaſt; and the whole company agreed, that if we had not looked out, we ſhould not have thought that the ſhip had any motion at that time.

*N.* And is not *that ſingle caſe* ſufficient to convince you that the earth may turn round, and carry us all about with it, and we feel nothing of its motion; eſpecially as the motion of the earth is much more regular and uniform than the motion of a ſhip, or any other machine that human art can contrive.

*E.* I confeſs it is.—But if the earth turns round, how comes it to paſs that a ſtone thrown directly upward, falls down again upon the very ſame place of the earth from which it was thrown up?—For, conſidering how large a globe the earth is, the parts of its ſurface muſt move very faſt, to turn round once every twenty-four hours. And if it turns at all, its motion muſt be eaſtward; becauſe the ſun, moon, and ſtars appear to move from Eaſt to Weſt. Now I ſhould imagine, that a ſtone or ball thrown directly upward from any place, would fall as far to the weſtward, of that place, as the place itſelf has got to the eaſtward, whilſt the ſtone was diſengaged from the earth, and riſing and falling in the ſame line.

*N.* Your obſervation is very ſenſible.—But you ought to conſider, that any body which is put into motion will perſevere in that motion till ſome thing or other turns it aſide, or ſtops its courſe. The ſtone partook of the earth's motion before it was diſengaged therefrom: the perſon who took it up had the ſame motion, by which means it was ſtill communicated to the ſtone; and therefore, its motion was as quick eaſtward while its was riſing and falling in the open air, as the earth's motion is: ſo that it could not miſs falling down again upon the ſame part of the earth. And although it would have appeared to a ſpectator to aſcend and deſcend in the ſame perpendicular line, yet its real motion was in a curve, and would manifeſtly have appeared ſo to an obſerver at reſt in the open air, on whom the earth's motion had no effect.

If a large boat was ſailing along, near the ſhore, two perſons oppoſite to one another in the boat might toſs a ball to each other, over and over acroſs the boat, to catch for their diverſion: and they would imagine it to be only going to and fro, from one perſon to the oppoſite, always in the ſame line: whereas 'tis certain, that the progreſſive motion of the ball, going from one ſide to the other, would be equal to the progreſſive motion of the boat: for if it was not, the oppoſite perſon (who had a progreſſive motion) could not catch it. And although it would appear to all the people in the boat, to move forward and backward in the ſame line, yet, to an obſerver on the ſhore, who is no way affected by the motion of the boat, the ball would be ſeen to have a zigzag motion, never returning to either perſon in the ſame line in which he toſſed it toward the other.

*E.* You have fully convinced me that there is nothing concluſive in my argument againſt the earth's motion.——And, in confirmation of what you ſaid about a body's being put into motion, that it will naturally perſevere therein, till ſome cauſe or other turns it aſide, or ſtops its courſe, I had once the experience thereof; and very painful it was. For, croſſing our river in the boat, I ſtood up when it was about half way over; and as its motion was uniform by the men pulling the rope, I was quite inſenſible both of its motion and my own. But when it ſtopt ſuddenly againſt the bank of the river, I fell forward on my face, and was much hurt by the fall. Whereas, if I had not, without knowing any thing of the matter, naturally perſevered in the motion given me by the boat, I could not have fallen when it was ſtopt.

*N.* Indeed, *Eudoſia*, you have given a true philoſophical account of the cauſe of your falling: and now I think we may, for the preſent, have done talking of this matter.

*E.* I think ſo too; for, ſpeaking of the fall makes me almoſt imagine I ſtill feel it.——But, pray, how do you prove that the earth is round like a globe?

*N.* I will prove *that* immediately. The ſun ſhines in through the window.——

*E.* What then?

*N.* Have patience a minute, and look at *this* ſmall globe in my hand, and the flat circular plate that lies on the table.——You ſee the globe may be hung by the thread which is faſtened to it. I now twiſt the thread, and hang the globe by it in the beams of the ſun; and the globe caſts a ſhadow on *that* upright board behind it. You ſee that the globe turns by the untwiſting of the thread; but let it turn how it will, it always caſts as round a ſhadow on the board as if it did not turn at all.——I now fix a thread to the edge of the flat circular plate, and hang the plate by the thread a little twiſted. You ſee, that when the broad-ſide of the plate faces the ſun, it caſts a round ſhadow on the board, as the globe did: but as it turns obliquely toward the ſun, by the untwiſting of the thread, its ſhadow is of an oval figure on the board; and when its edge is turned toward the ſun, its ſhadow on the board is only a narrow ſtraight line.

*E.* All this is plain; but I cannot imagine what you are to infer from it.

*N.* The earth always caſts a ſhadow toward that part of the heaven which is oppoſite to the ſun; and the moon appears as flat to us as the board on which the ſhadow of the ſmall globe was projected. When the earth's ſhadow falls upon the moon, we ſay, *the moon is eclipſed.* Theſe eclipſes happen at all different times of the twenty four hours; and, conſequently, when all the different ſides of the earth are ſucceſſively turned toward the Sun. But the earth's ſhadow on the moon is always bounded by a circular line; and therefore, it is plain, that the earth muſt be of a globular ſhape. ——For, if it were ſhaped like *this* flat circular plate, its ſhadow on the moon could never be circular but when its broad-ſide was turned directly toward the ſun. At other times, the ſhadow would be either of an oval figure, or only a ſtreight line, as you have ſeen on the board. There are ſeveral other ways of proving that the earth is round; but I believe you are ſatisfied that it is ſo, from what I have now ſhewn you.

*E.* I am entirely ſatisfied, and therefore more proofs would be ſuperfluous. But I ſhould now be glad to know how you prove that the earth turns round; and that the ſun does not go round the earth.

*N.* Before I proceed to the demonſtration, I will aſk you a very plain queſtion, which I hope you will not take amiſs, as I have not the leaſt deſign to affront you.

*E.* Indeed I do not believe you have; and therefore I beg you will aſk it.

*N.* Suppoſe you put a ſmall bird on a ſpit, and put it to the fire; whether it is the beſt way to turn the ſpit round with the bird, or to let the ſpit ſtand ſtill, and move the fire round about it?

*E.* Your queſtion almoſt ſurpriſes me,——for, not to ſpeak of the wiſdom of *man*, ſure no *woman* of common ſenſe could be ſo abſurd, as to ſet about contriving how to make the large fire and grate be carried round the ſpit.

*N.* True, *Eudoſia.*—Now I can aſſure you, that the ſun is, at leaſt a million of times as big as the earth; and is therefore more unfit to be moved round the earth, than a great fire, and the grate that holds it, is to be moved round a ſmall bird on a ſpit.——And as no *man* in his ſenſes would go to work on ſuch an abſurd attempt, would it not be horrid blaſphemy to ſuppoſe, that the DEITY, who is the very eſſence of wiſdom and perfection, would do ſo.

*E.* Heaven forbid the thought! the bare mentioning ſuch a thing is enough to chill one's blood.——Were I ſure, that the ſun could be proved to be a million of times as big as the earth, I ſhould aſk no further demonſtration of the ſtability of the ſun and the motion of the earth; becauſe I ſhould naturally conclude, that the ſun is a million of times more unfit to move than the earth is. And, as the moſt ſuperlative degree of wiſdom and reaſon is in the Deity, 'tis impoſſible for me to imagine he could do any thing that is irrational.—My belief is, that he always makes uſe of the feweſt, moſt ſimple, and moſt rational means, to produce the greateſt, moſt noble, and moſt aſtoniſhing effects; ſuch as his infinite goodneſs and beneficence to his creatures has rendered conducive to their welfare, in numberleſs inſtances.

*N.* He certainly does.——And now I will prove to you, that the earth turns round every twenty-four hours; not upon any material axis, but on an imaginary ſtraight line within itſelf, paſſing through its center, and terminating in its North and South points, which are called its *North* and *South poles*; as an orange would turn round in the open air, if you firſt ſet it a whirling, and then throw it off your hand in the air.

Pl. I.

Fig. 1.

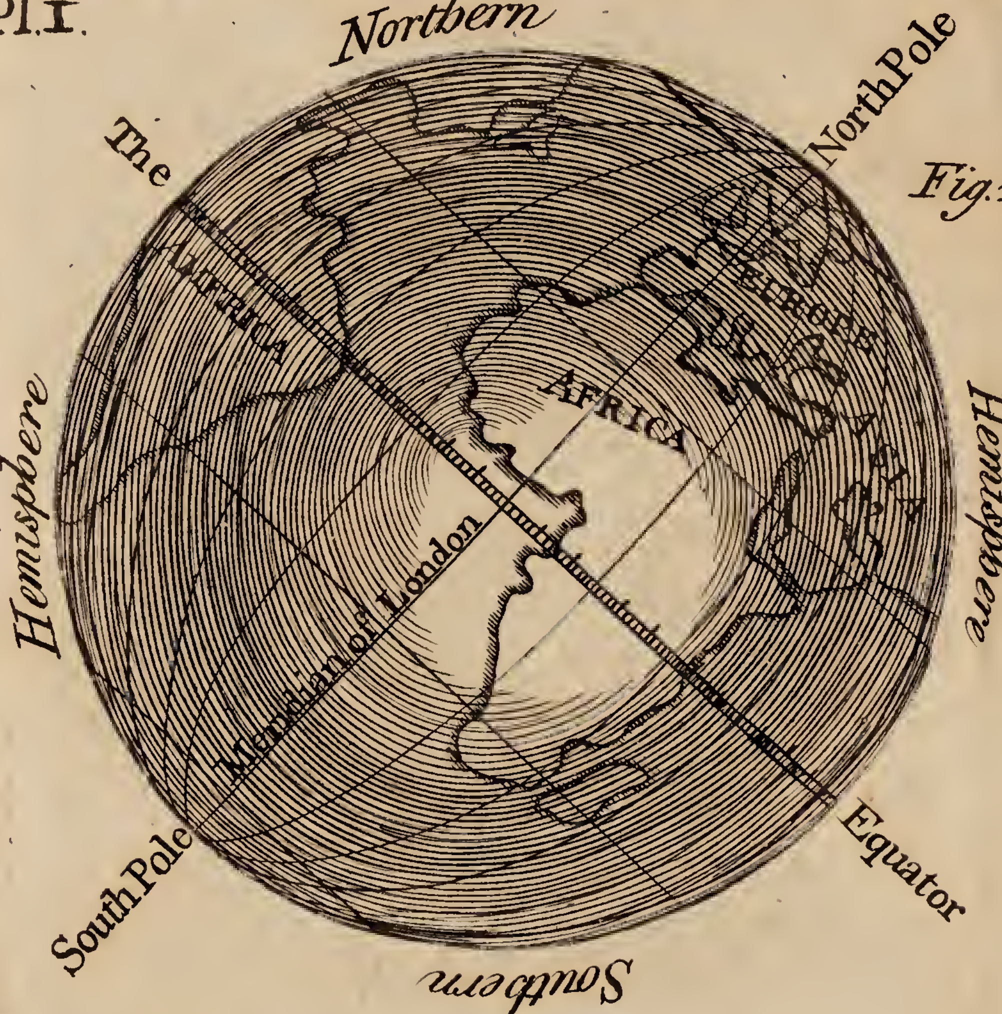
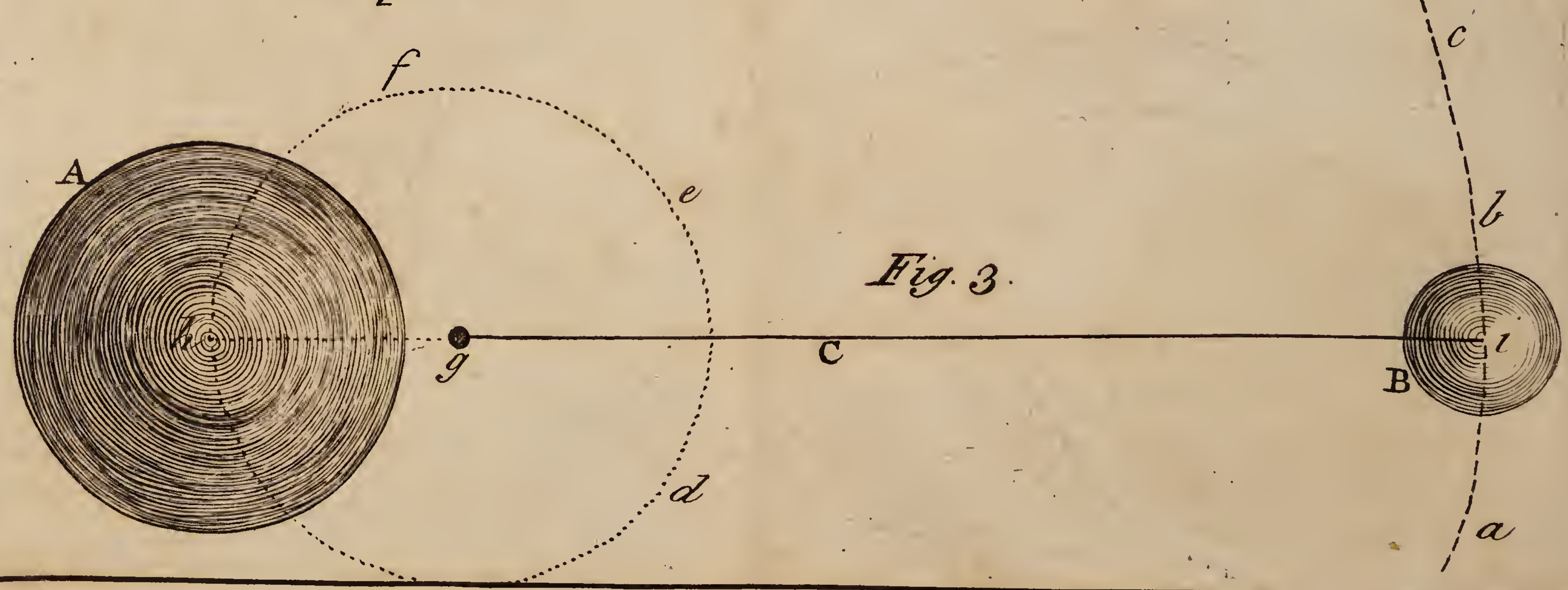


Fig. 2.

Fig. 3.



Water naturally runs downward, all around the earth, from theſe parts which are higheſt, or fartheſt from the center, toward thoſe which are loweſt or neareſt to it: and this is cauſed by the power of the earth's central attraction, which draws the water and all other bodies that way. Now, if the earth was perfectly round, and ſmooth like a poliſhed globe, all the parts of its ſurface would be equidiſtant from its center; and water could never run upon it. About three-fourth parts of the earth's ſurface is covered with the ſeas, which join or communicate with each other. And if the earth had no motion round its axis or center, the attractive force (which is equal all around at equal diſtances from the center) would cauſe the ſurface of the ſeas to be of a perfectly round and globular form.

*E.* Undoubtedly it would: for then, as every particle of the water's ſurface would be drawn with equal force toward the earth's center, and theſe particles do touch each other; none of them could get nearer the center than their neighbouring ones.

*N.* Right.——And now, ſuppoſing the earth to be at reſt, and the ſurface of the oceans and ſeas to be perfectly globular; what do you think the conſequence would be, if the earth ſhould begin, and continue to turn round on a line within itſelf, as if it turned on a real axis?

*E.* Let me think a little.——I have obſerved, that when our maid took her mop out of a pail of water, the head of the mop was round: but when ſhe began to trundle it on her arm, it immediately became flattened at the parts of the ſtick which were even with its ſurface; and it ſwelled out in the middle——Pray, brother, if I may be allowed to make a very odd ſort of a compariſon, may not an imaginary line in the heart of that part of the ſtick which is within the mop be called the axis round which the mop turns; as you have told me that ſuch a line within the earth, from its North to its South poles, is called the axis of the earth?——If ſo, ſeeing that the waters on the earth are of as yielding a nature as the cotton of the mop; I apprehend, that if the earth turned round its axis, the ſurface of the ſeas about the poles would become flat, and the ſurface of the ſeas which are fartheſt from the poles would ſwell out, all around: and ſo, the figure of the earth would be like that of a whirling mop.

*N.* No philoſopher could have made a more apt compariſon, nor have drawn a better concluſion from it. When I told you before, that the earth is round, I did not mean that it is ſtrictly ſo; although, at the diſtance of the moon, it would appear to be round, as its ſhadow on the moon does to us. I do not here conſider the hills as any thing, becauſe they are ſo little in compariſon to the whole bulk of the earth, that they take off no more from its roundneſs in general, than grains of duſt do from the roundneſs of *that* ſmall three inch globe which you ſee on the table. *It* is quite round, and covered all over with paper, on which there is a map of the land and water on the earth's ſurface. The middle line (ſee Fig. 1. of PLATE I.) circle, or that is drawn round it, is called the *Equator*, which divides the globe into two equal parts, called the *Northern* and *Southern Hemiſpheres*, or half globes. The *North* and *South Poles* are the *middle Points* of the North and South hemiſpheres, each pole being a quarter of a circle diſtant from each point of the equator, all around: and a ſtraight line drawn through the center from pole to pole, is called *the axis* of the globe.

If the thin papers were ſcraped off from the poles, and almoſt half way round them toward the equator, the globe would be a little flattened at the poles, and comparatively ſo much ſwelled out about the equator but if it were then viewed from the diſtance of ſix or ſeven feet, it would ſtill appear to be round.

*E.* I believe it would :—but what of all this ?

*N.* From actual meaſurement and obſervation, the earth is proved to be a little flattened at the poles, and ſwelled out about the equator ; the equatoreal diameter of the earth being thirty-five miles longer than the axis or polar diameter. This you may think a great deal, but it is very little when compared with the bulk of the earth, as you will eaſily judge when I tell you, that no leſs than 25,000 Engliſh miles would meaſure it round : and the higheſt mountains that are known are not three miles of perpendicular height.——Now, as water naturally runs downward, if the earth had no motion on its axis to keep up its figure, the water of the ſeas would run from the higher parts about the equator, to the lower parts about the poles, and overflow the polar regions for many hundred miles all around ; and even Britain itſelf would be laid ſeveral miles under water.

*E.* This is a very plain caſe : and the not returning of the waters from the ſeas about the equator, is to me an evident proof of the earth's turning round its axis ; without which, the ſurface of the waters would become of a general roundneſs, as I ſaw the head of the mop do when the maid left off trundling it.——And now it ſeems plain, that the Almighty muſt have made the rigid earth as much higher about the equator, than the land is about thoſe places near the poles, as the earth's quick motion about the equatoreal parts would cauſe the waters to riſe there. For I ſee by the globe, that there are great quantities of land about the equator, and many ſmall iſlands in the ſeas, which are not overflowed.

*N.* The more you know of theſe matters, *Eudoſia*, ſtill the greater reaſon you will have to admire the power, and adore the wiſdom and goodneſs of the Deity.

*E.* Indeed, brother, I believe I ſhall.——And I already begin to think, that if an atheiſt would be perſuaded to learn Aſtronomy, it would ſoon cure him of his infidelity.

*N.* So I have often thought, ſince I knew any thing of the matter.

*E.* I think you told me, that almoſt three-fourth parts of the ſurface of the earth is covered with ſeas; and by looking on *that* ſmall globe, I imagine it may be ſo. But you have not yet told me, how it is known, that the earth's circumference is 25,000 Engliſh miles; and perhaps I ſhould not be able to underſtand it if you did.

*N.* The bulk of the earth is aſcertained by (what is called) Geometry, and could not have been known by any other kind of learning. And as you do not yet underſtand any part of that ſcience, I ſhould only confound your head by talking to you on that ſubject at preſent.

*E.* Your ſaying, "*at preſent*," gives me ſome hopes, that you will endeavour to inſtruct me in that branch of ſcience afterward.——But can you tell me juſt now, how many miles of the earth is land; and how many are covered with the ſeas?

*N.* The ſurface of the earthy part of our great globe is divided into four great tracks or ſpaces, called *Europe*, *Aſia*, *Africa*, and *America*; as you ſee them laid out on the ſmall three inch globe.

According to meaſurement of the beſt maps, the ſeas and unknown parts of land contain 160,522,026 ſquare miles: the inhabited parts 38,990,569; *Europe* 4,456,065; *Aſia* 10,768,823; *Africa* 9,654,807; *America* 14,110,874. In all, 199,512,595; which is the number of ſquare miles on the whole ſurface of our globe.

*E.* I admire the prodigious bulk of the earth; but infinitely more ſo, the power that muſt have ſet it in motion at firſt.

*N.* Nothing is great or ſmall but in compariſon. We are very big when compared with animals which can be ſeen only by the help of a microſcope: the earth is big indeed when compared with ourſelves, who live upon it: the planet Jupiter is a thouſand times as big as our earth, and the ſun is more than a thouſand times as big as Jupiter.——If you ſo juſtly admire the power that put our ſmall planet the earth into motion, how much more muſt you admire the power which put the whole planetary ſyſtem round us in motion!

*E.* I ſink into nothing, in my own mind. Alas, what have we to be proud of? If I had been proud before, Aſtronomy would have cured me effectually of it.

*N.* Indeed it might cure any one of pride: and I believe no aſtronomer can be either proud or impious. —But hark!—the bell rings for breakfaſt,—I thought to have ſatisfied your query about the ſun, but muſt leave it till the next opportunity. Be ſure then to put me in mind of it, and afterwards to talk about the ſolar ſyſtem.

*E.* I believe I ſhall have no occaſion to re-mind you.

# DIALOGUE II.

## *On the* BALANCE *of* NATURE *and the* SOLAR SYSTEM.

*Neander.*

WELL, ſiſter; what became of you yeſterday after breakfaſt? I went to my room immediately after, thinking you would follow me, that we might have a little converſation. But, inſtead of *that*, you have left me quite alone; for I never ſaw you the whole day afterward, except at dinner and ſupper.

*Eudoſia.* Indeed, brother, I was ſo much pleaſed with what you told me yeſterday morning, that I was willing to make the moſt and beſt of it that I could; and therefore employed the reſt of my time in writing down every thing that I could remember.

*N.* I am very glad of it; and now I find you intend to emulate a young lady of quality; who, laſt year, attended a courſe of lectures on experimental philoſophy at Tunbridge Wells; and always, when ſhe went home, wrote down what ſhe had heard and ſeen. The perſon who read the lectures informed me, that he was (though with ſome difficulty) favoured with a ſight of the young Lady's manuſcript; and aſſured me, that ſhe had therein given a very good account of the machinery and experiments. I hope you will not refuſe to ſhew me yours, every day, as we proceed.

*E.* You ſhall always ſee it, were it only for this ſelfiſh reaſon, that you may correct and amend what is wrong in it; and then I ſhall reap the advantage. I will now repeat my yeſterday's query: To what is the ſun fixed? for you have convinced me that he does not move round the earth.

*N.* The ſun is not fixed to any thing at all; nor is it any way requiſite he ſhould. I told you that the falling of bodies to the earth is ſolely cauſed by the earth's attraction.

*E.* I remember it very well; and it ſeems plain to me, that their falling toward the earth's center, on all ſides of it, is a demonſtrative proof of the earth's attraction. For what elſe could poſſibly determine bodies to fall, on oppoſite ſides of the earth, in directions quite contrary to one another?

*N.* Right *Eudoſia*, you are a philoſopher already: and I ſhall have very great pleaſure in teaching you, at leaſt, the rudiments of Aſtronomy.

The tendency of bodies to fall, is called their *Gravitation*, and the power which gives them that tendency, is called *Attraction.* Now, ſuppoſing the ſun (PLATE I. *Fig.* 2.) to be the only body that exiſts in univerſal ſpace, and that he is put into any part of open ſpace, pray, to what other part of ſpace do you think he would fall?

*E.* I think he could not fall to any other part of ſpace at all, becauſe there would be no other body to attract him; and, therefore, I imagine, that he would always remain where he was placed, *ſelf-balanced on his center* ; as my favourite poet *Milton* elegantly expreſſes it, concerning the earth.

*N.* Your obſervation is ſtrictly juſt. And now, to lead you further on, I tell you, that the ſun's attraction reaches many millions of miles all around him ; and that all bodies attract each other according to their reſpective quantities of matter ; that is, according to the number of particles of matter they are compoſed of. I have already told you, that the ſun is a million of times as big as the earth : and as the ſun and earth are within the reach of each other's attraction ; whether do you think, that the ſun ſhould fall to the earth, or the earth to the ſun !

*E.* I think, that if the ſun contains as much more matter than the earth does, as he is bigger than the earth, it is a million of times more reaſonable, that the earth ſhould fall to the ſun, than that the ſun ſhould fall to the earth.

*N.* Right again, ſiſter ; but now I muſt inform you, that the ſun is not ſo compact or denſe a body as the earth is ; and therefore he doth not contain as much more matter than the earth does, as he is bigger than the earth. But his quantity of matter is more than 200,000 times as great as the earth's : and, conſequently, he attracts the earth more than 200,000 times as ſtrongly as the earth attracts him.

*E.* Then I ſhould think, that the ſun and earth would naturally fall toward each other, and come together at laſt : only, that the earth would fall 200,000 times as faſt toward the ſun, as the ſun would toward the earth.

*N.* And ſo they would, if there were nothing to hinder them.

*E.* And what is it that hinders them ?

*N.* I will begin to anſwer your queſtion by aſking you one.——Did you ever put a pebble into a ſling, and whirl it round your head?

*E.* Yes, Sir, when I was a child.

*N.* And did you feel no tendency in the pebble to fly off from the ſling?

*E.* O, yes! and the moment I let the ſtring ſlip from my hand, away the pebble flew.——I likewiſe remember, that the faſter I whirled the ſling, the greater was the tendency of the pebble to fly off; and that I was obliged to pull the ſtring ſo much the ſtronger to keep the pebble from doing ſo.

*N.* That obſervation will be of more ſervice to you by and by, than you at preſent think of; but it would be too ſoon to tell you juſt now how it will.

*E.* I will wait till you find it proper to tell me. But I am almoſt impatient to know what you are to infer from the pebble and ſling.

*N.* All bodies that move in circles have a conſtant tendency to fly off from theſe circles; which tendency is called their *centrifugal force.* And, in order to keep them from flying off, there muſt be an *attractive force* at the centers of theſe circles, equal to the centrifugal force of the moving bodies. The earth goes round the ſun once a year, in an orbit or path which is nearly circular; and it would as naturally fly off from its orbit, if the ſun did not attract it, as the pebble flew out of the orbit that it deſcribed round your head, when you quitted your hold of the ſtring.

*E.* This is new doctrine to me; for you never told me before, that the earth goes round the ſun. The earth then has two motions, one round its axis in twenty four hours, and one round the ſun in a year.—Can you prove as clearly, that the earth goes round the ſun, as you have proved that it turns round its axis?

*N.* I will prove it negatively juſt now, and poſitively afterward. If the earth had no motion round the ſun, it could have no centrifugal force, to hinder it from falling to the ſun, by its own weight or gravitation, which is conſtituted by the power of the ſun's attraction.

*E.* I ſee that the earth's motion round the ſun is indiſpenſibly neceſſary, and am therefore ſatisfied that it does exiſt. But I think the ſun would require ſome motion too, in order to give him a centrifugal force, without which, it ſeems to me, that big as he is, the earth's attraction would pull him out of his place. For, I remember, that the pebble and ſling pulled my hand ſo ſtrongly, although the pebble was ſmall, that I could not poſſibly keep my hand ſteady whilſt the pebble was in motion.

*N.* Well done, ſiſter.——The ſun really moves in an orbit as well as the earth; and the ſun's orbit is as much leſs than the earth's, as his quantity of matter is greater than the earth's. And, as both theſe bodies go round their orbits in the ſame period of time, the ſun moves as much ſlower than the earth does, as his quantity of matter is greater than the earth's. So, what is wanting in the velocity or ſwiftneſs of the ſun's motion, is made up by his quantity of matter; and what is wanting in the earth's quantity of matter, is made up by the ſwiftneſs of its motion in its orbit; on which account, their centrifugal forces are equal to each other's attractions; and, as theſe attractions keep them from flying out of their orbits by their centrifugal forces, ſo theſe forces keep them from falling towards each other by their mutual attractions.——And this is, what we call, *the great balance of nature.*

*E.* This is a new light to me, and a moſt delightful one it is. But, although I think I underſtand it, I wiſh you would further explain it by a figure.

*N.* Here is a figure (PLATE I. Fig. 3.) which I drew laſt night on purpoſe for you; in which, ſuppoſe *A* to repreſent the ſun, *B* the earth, and *C* the line of direction in which the ſun and earth mutually attract each other: in which line, take a point *g*, as much nearer the center of *A* than the center of *B*, as *B* contains leſs matter than *A*; the center of *A* being at *h*, and the center of *B* at *i*. If *A* and *B* were allowed to fall againſt each other, by the power of their mutual attractions, then, in the time that *A* would fall through the ſpace *h g*, *B* would fall through the ſpace *i g*; and both theſe bodies would meet at *g*, becauſe *B* would fall as much faſter than *A*, as its quantity of matter (and conſequently its attractive force) is leſs than that of *A*.

But, in the time the ſmall body *B* goes round the large circle *a b c*, the great body *A* goes round the ſmall circle *d e f*; by which motion, each of theſe bodies acquires a centrifugal force equal to the attractive force of the other; and the point *g* is the center of both the circles which the bodies deſcribe; and is called *their common center of gravity*, or the center of gravity between them.

*E.* I ſhould be glad to know why it is ſo called.

*N.* I will tell you.——Suppoſe *A* and *B* to be two balls of different quantities of matter, and conſequently of different weights; and that thoſe balls are connected by a ſmall inflexible wire, *C.* that has no weight at all (if you can imagine a wire to have no weight, like the immaterial line in which the ſun and earth attract each other). Hang the wire by a thread fixed to the point *g*, which point is as much nearer the center of the great ball *A*, than it is to the center of the little ball *B*, as the weight of *B* is leſs than the weight of *A*: and then, theſe balls will ſupport and balance each other, like different weights at the two ends of a common ſteelyard, by which you have ſeen meat weighed at home, after it was brought from market. The point *g* may repreſent the center or axis of the ſteel-yard, which bears the weights that are at both its ends. And, as gravity and weight are ſynonymous terms, the point *g*, or center of the ſteelyard, is not improperly termed the center of gravity of the weights *A* and *B*.

*E.* I underſtand you perfectly well; and am much obliged to you for the pains you have taken hitherto, to make every thing ſo plain to me.

*N.* And, now, if you twiſt the thread, by which the wire and balls are ſuſpended at the point *g*, the untwiſting of the thread will cauſe them both to go round; the great ball in the ſmall circle *d e f*, and the little ball in the great circle *a b c*; and the center of gravity *g* between them will remain at reſt.

*E.* From which I infer, that the center of gravity between the ſun and the earth is a motionleſs point.

N. And your inference is right.

*E.* I was juſt going to aſk you a queſtion, but am very glad a lucky thought prevented me; for it would have been quite childiſh.

*N.* Remember what M. *Beaugrand* told you when he began to teach you French; *Never fear, but ſpeak out, right or wrong: if you are wrong I will not laugh at you; I will put you right.*——Now tell me what your intended queſtion was?

*E.* As we were obliged to hang the wire and balls by a thread, to ſupport their center of gravity; I was juſt about to aſk, what is it that ſupports the center of gravity between the earth and the ſun?

*N.* Well:——And what was the lucky thought that prevented your aſking *that* queſtion?

*E.* I immediately recollected, that we muſt ſupport the center of gravity between the two balls, becauſe, otherwiſe, they would have fallen to the great earth by the power of its attraction. But, as there is no greater body than the ſun and earth to attract them, they could fall no way but toward each other; and, therefore, the common center of gravity between them needs nothing to ſupport it.

*N.* If you had asked the queſtion, I ſhould have told you the very ſame thing.

*E.* If all the parts of aſtronomy are as eaſily learnt as thoſe which you have already taught me, I ſhall have no reaſon to be vain, even if I become a tolerable good aſtronomer by your inſtructions.

*N.* I dare not ſay they are; but I will make every part of it, which I inform you of, as plain as I can.

*E.* You have already told me that the earth is a planet, and that there are other planets beſides, which go round the ſun.

*N.* Yes; there are five beſides our earth: and they are called *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*.

*E.* Then, our ſun muſt be their ſun too.

*N.* It is really ſo; and enlightens them all.

*E.* I could never believe that the Almighty does any thing in vain; and therefore I begin to think, that all the other planets are inhabited as well as our earth. For, to what purpoſe could the ſun ſhine upon lifeleſs lumps of matter, if there were no rational creatures upon them to enjoy the benefit of his light and heat?

*N.* Ay, why indeed?——And I will tell you one thing more, which will confirm your belief that they are inhabited.——They turn round their axes, as our earth turns round its axis; for which plain reaſon, they have days and nights as our earth has: and the two which are fartheſt from the ſun, namely, *Jupiter* and *Saturn*, and which, conſequently, have much leſs light than our earth has; have moons to enlighten them, *Jupiter* four, and *Saturn* five.

*E*. To me, this is a poſitive proof of their being inhabited; and is enough to make us think, that we are but a ſmall part of the creation, or of the favourites of heaven: and that all the regards of Providence are not attached to our diminutive concerns.

*N*. The Divine Providence is univerſal. GOD loves his creatures, as is manifeſt by what he hath done for us, who, perhaps, deſerve leſs of his favour than the inhabitants of all the other planets do, taken together. ——It is as eaſy to him to take care of thouſands of millions as of one individual, and to liſten to all their various requeſts.——On account of his omnipreſence, nothing can eſcape his notice; and on account of his omniſcience, nothing can eſcape his knowledge!

*E*. And, as his omnipotence may be inferred from his works, ſo I have often thought, that his goodneſs may be inferred from his power. For, as he had power enough to make the world, he certainly has power enough to puniſh the world: and, conſequently, if his goodneſs were not equal to his power, he would puniſh us ſeverely for breaking his laws.

*N* I believe, ſiſter, a more juſt inference was never made.

*E*. Do all the planets go round the ſun in a year, as our earth does?

*N*. No; thoſe which are neareſt the ſun go ſooneſt round him, and thoſe which are fartheſt from him are longeſt in performing their circuits.

*E*. And do they all move round the center of gravity between the ſun and them, as round a fixed point?

*N*. They do.

*E*. Then, as the times of their going round the ſun are ſo various, I cannot ſee how the ſun can deſcribe any regular circle round the common center of gravity between him and them all. For, in order that the ſun ſhould move regularly round ſuch a circle, I think all the planets would need to be joined together in one maſs.

*N.* 'Tis very true; and we muſt proceed by degrees. What I ſhowed you by the figure was only on ſuppoſition, that there is but one planet belonging to the ſun. But as there are ſix belonging to him, and going round him in very different periods of time, he is only agitated (as it were) round the common center of gravity of the whole ſyſtem; and deſcribes no regular or perfect circle round it, but is ſometimes nearer to it, and at other times further from it, according as he is attracted by a greater or ſmaller number of planets toward any ſide of the heavens.

*E.* In what times do all the planets go round the ſun?

*N.* *Mercury* in 87 days, 23 hours, of our time; *Venus* in 224 days, 17 hours; the *Earth* in 365 days, 6 hours; *Mars* in 686 days, 23 hours; *Jupiter* in 4332 days, 12 hours; and *Saturn* in 10,759 days, 7 hours; all the ſame way, from Weſt, by South, to Eaſt.

*E.* And do you know what their diſtances from the ſun are?

*N.* Their comparative diſtances from the ſun have been known long ago, both by the laws of nature, and by obſervation, and are as follows.——If we ſuppoſe the earth's diſtance from the ſun to be divided into 100,000 equal parts, Mercury's diſtance from the ſun will be equal to 38,710 of theſe parts; Venus's diſtance 72,333; Mars's diſtance 152,369; Jupiter's diſtance 520,096; and Saturn's diſtance 954,006.

*E.* And can you tell how many miles are contained in theſe parts?

*N.* Not ſo exactly as we could wiſh; yet aſtronomers have come much nearer to the knowledge thereof, by the late tranſit of Venus over the ſun, on the 6th of June 1761, than ever they were before.——But we muſt wait with patience till the year 1769, when there will be a much better tranſit of that planet over the ſun, in the evening of the third of June; by which means, if it be properly obſerved at different places of the earth, the dimenſions of the whole ſyſtem will be very nicely known. And the aſtronomers will do well to embrace *that* opportunity, becauſe there will not be ſuch another in a hundred years afterward. The method of finding theſe diſtances by the tranſit is purely geometrical; which, as you have not yet learned any thing of geometry, I cannot at preſent make you underſtand.

*E.* But, tell me what theſe diſtances are, as deduced from the late tranſit in June 1761.

*N.* Mercury's diſtance from the ſun is 36,841,468 Engliſh miles: Venus's diſtance 68,891,486: the Earth's diſtance 95,173,000: Mars's diſtance 145,014,148: Jupiter's diſtance 494,990,976: and Saturn's diſtance 907,956,130.

*E.* Theſe diſtances are ſo immenſely great, that I can form no ideas of them.

*N.* Then I will endeavour to render them more familiar to you. For we are generally ſo much uſed to ſpeak of thouſands and millions, that we have almoſt loſt the idea of the numbers they contain.

Suppoſe a body, projected from the ſun, ſhould continue to fly at the rate of 480 miles every hour, (which is much about the ſwiftneſs of a cannon-ball) it would reach the orbit of Mercury in 8 years, 276 days; of Venus in 16 years, 136 days; of the earth in 22 years, 226 days; of Mars in 34 years, 165 days; of Jupiter in 117 years, 237 days; and of Saturn in 215 years, 287 days.

*E.* Amazing to think, that a cannon-ball would be upwards of 200 years in going from the ſun to the remoteſt planet of the ſyſtem! The diſtance muſt indeed be immenſe!

*N.* Great as you think it, (and to be ſure great it is) yet ſome of the comets go almoſt fourteen times as far from the ſun as Saturn is: notwithſtanding which, they are then nearer to the ſun than to any of the ſtars. For, if any comet ſhould go as near to any ſtar as it is to the ſun, when fartheſt from him, it would be as much attracted by that ſtar as it is then by the ſun; and its motion being then toward the ſtar, it would go on, and become a comet to that ſtar; and we ſhould never hear of it any more.——And now, *Eudoſia*, what do you think of the diſtance of the ſtars?

*E.* I am loſt in wonder!——But ſuppoſing there were no comets, pray is there any other way by which we might know that the diſtance of the ſtars is ſo inconceiveably great?

*N.* I ſhall only tell you of one way.——If we are at a great diſtance from two neighbouring houſes, they ſeem to be ſmall, and at a little diſtance from one another. But, as we approach nearer and nearer to them, they ſeem to grow bigger and bigger, and the diſtance between them to encreaſe. You know this.

*E.* Very well: pleaſe to proceed.

*N.* The earth goes round the ſun every year, in an orbit, which is upwards of 190 millions of miles in diameter.——Hence, we are 190 millions of miles nearer to ſome of the ſtars juſt now, than we were half a year ago, or ſhall be half a year hence: and yet, for all that, the ſame ſtars ſtill appear to us of the ſame magnitude, and at the ſame diſtance from each other, not only to the bare eye, but alſo when viewed by the niceſt made inſtruments.——Which ſhews very plainly, that the whole diameter of the earth's orbit is but a dimenſionleſs point in compariſon to the diſtance of the ſtars.

*E.* All further proofs of the immenſe (and, I ſhould think, almoſt infinite) diſtance of the ſtars, would be ſuperfluous. But, as we were talking about the comets, pray, are they not dangerous?——We are always frightened when we hear of their appearing, leſt their fiery trains ſhould burn the world.

*N.* That is owing to people's not knowing better. The orbits of the planets are all nearly in the ſame plane, (as if they were circles drawn on a flat board) but the orbits of the comets are elliptical, and all of them ſo oblique to the orbits of the planets, and alſo to each other, that no comet can ever touch a planet. And, as to thoſe appearances, which are called the tails of the comets, they are only thin vapours, which ariſe from the comets, and which could not hurt any planet, if it ſhould happen to go through that vapour when the comet is croſſing the plane in which the planet's orbit lies. If theſe trains were fire, we could not ſee any thing through them that is beyond them. For, if you hold a candle between you and any object, you cannot ſee that object through the flame of the candle; but the ſmalleſt ſtars are ſeen through the tail of a comet.

*E.* This is comfortable doctrine indeed.

*N.* Beſides, you know that the world muſt be converted to Chriſtianity before it be burned; which, we can hardly believe, will be within the time that you and I can live, according to the ordinary courſe of nature.

*E.* Alas, brother! our people who go into thoſe remote parts where Chriſtianity was never heard of, behave ſo unjuſtly and cruelly to the poor natives, as might rather frighten them from the chriſtian religion, than induce them to embrace it. I confeſs I am not at all ſurpriſed, when I hear, that the native Americans riſe ſometimes in large bodies, and deſtroy thoſe who call themſelves chriſtians, on account of their barbarous ways of uſing that people.

*N.* It is not at all to be wondered at: for their principles are, *Good for good*, and *Evil for evil.*

*E.* As it makes me melancholy to think or ſpeak of theſe things; I beg we may reſume our intended ſubject. Conſidering how far the planets are from the ſun, and in what times they go round him, they muſt move very faſt in their orbits. I ſhould be glad to know how many miles they move every hour.

*N.* Mercury moves 109,699 Engliſh miles every hour; Venus, 80,295; the Earth, 68,243; Mars, 55,287; Jupiter, 29,083; and Saturn, 22,101.

*E.* And ſo we are carried 68,243 miles every hour, along with the earth in open ſpace, without being in the leaſt ſenſible of that rapid motion.

*N.* We are indeed, ſiſter.

*E.* And can you tell me what the magnitudes of the ſun and planets are?

*N.* When the diſtance of an object is known, there are eaſy geometrical rules for deducing its real bulk from its apparent bulk.——According to the fore-mentioned diſtances, the ſun's diameter is 893,760 miles, (and conſequently he is 1,410,200 times as big as the earth); Mercury's diameter, 3100; Venus's, 9360, the Earth's, 7970; Mars's diameter, 5150; Jupiter's, 94,100; and Saturn's diameter, 77,990 Engliſh miles.

The moon's diſtance from the earth's center is 240,000 Engliſh miles, her diameter is 2170; ſhe moves (with reſpect to the earth) 2290 miles in her orbit every hour; and ſhe goes round the earth, from change to change, in 29 days, 12 hours, 44 minutes.

*Jupiter* has four moons, going round him in different times and at different diſtances. His firſt, or neareſt moon, goes round him in 1 day, 18 hours, 36 minutes; the ſecond, in 3 days, 13 hours, 15 minutes; the third, in 7 days, 3 hours, 59 minutes; and the fourth, or fartheſt moon from him, in 16 days, 18 hours, 30 minutes.

*Saturn* has five moons, the neareſt of which goes round him in 1 day, 21 hours, 19 minutes; the ſecond, in 2 days, 17 hours, 40 minutes; the third, in 4 days, 12 hours, 25 minutes; the fourth, in 15 days, 22 hours, 41 minutes; and the fifth, or outermoſt, in 79 days, 7 hours, 48 minutes. This planet is encompaſſed by a broad thin ring, ſet edge-ways round it, and the diſtance of the ring from the planet is equal to the breadth of the ring. The ſun ſhines for almoſt 15 of our years together on the northern ſide of the ring, then goes off, and ſhines as long on the ſouthern ſide of it: ſo there is but one day and one night on each ſide of the ring, in the time of Saturn's whole revolution about the ſun, which takes up almoſt 30 of our years.

*E.* A long day and night indeed, for the inhabitants of the ring, if any ſuch there be. Undoubtedly, if it is inhabited, it muſt be by beings very different from us; as we have no reaſon to believe, but that the Deity has accommodated their days and nights as well for them as he has ours for us.——But you told me, that the other planets turn round their axes, as our earth does: do they all turn round the ſame way, or eaſtward, ſo as to cauſe the ſun and ſtars appear to go round weſtward; and in what times do they turn round?

*N.* By viewing them with good teleſcopes, we ſee ſpots upon moſt of them, which adhere to their ſurfaces, and appear and diſappear regularly on their oppoſite ſides. By the motions of theſe ſpots, which are all eaſtward, we know that Venus turns round her axis in 24 days, 8 hours, of our time; by which divide 225 of our days, the time in which Venus goes round the ſun, or the length of her year; and we ſhall find, that her year contains only 9¼ of her days. Mars turns round in 24 hours, 40 minutes of our time; and Jupiter in 9 hours, 56 minutes. We cannot tell in what times Mercury and Saturn turn round their axes, becauſe no ſpots have been ſeen upon them, even by the beſt teleſcopes.—— The ſun turns round his axis in 25 days, 6 hours, from Weſt to Eaſt, alſo.

*E.* Why ſhould the ſun turn round? for, as he is the fountain of light, he can have no days and nights.

*N.* To turn away his dark ſpots from long facing the planets, and thereby to diſpenſe his light the more equally all around him to the planets. But, are you not tired by this morning's long converſation?

*E.* Far from it, brother, though I am ſure you may. But what ſhall I do? for I fear I cannot remember much of what you have told me this morning, ſo as to write it down.

*N.* Never mind that, *Eudoſia*; for I believe I ſhall publiſh theſe our converſations, for the ſake of other young ladies; many of whom are, no doubt, willing to learn Aſtronomy, but have no body to teach them. And then you can have the whole together in print.

*E.* If you do, Sir, I muſt inſiſt upon your not mentioning my name.

*N.* Your deſire ſhall be complied with: and in concealing your real name, I ſhall alſo conceal my own.

⁂

# DIALOGUE III.

## On GRAVITY and LIGHT.

*Neander.*

SO, ſiſter; I find you are not willing to ſlip the morning opportunity, when we can be undiſturbed, and by ourſelves. Have you made any remarks upon our laſt converſation?

*Eudoſia.* Yes, brother.——In the firſt place, I remember you told me, that the planet *Mercury* moves 109,699 miles every hour in its orbit, and *Saturn* only about 22,000. I obſerved likewiſe, that the further the planets are from the ſun, they not only take longer times to go round him, but alſo move ſlower in every part of their reſpective orbits. Can you aſſign any reaſon for this?

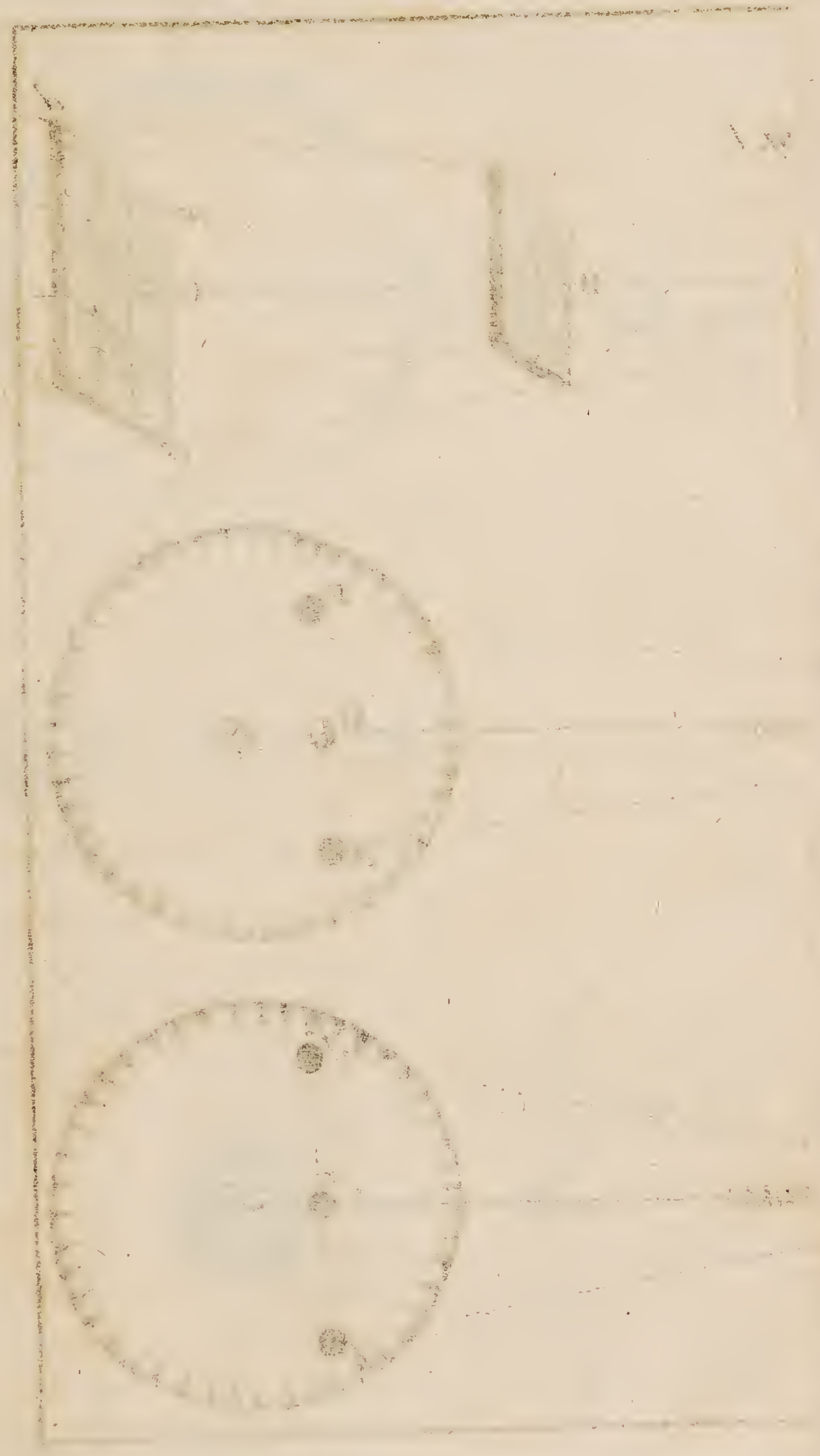
*N.* The nearer that any planet is to the ſun, the more ſtrongly it is attracted by the ſun; the farther any planet is from the ſun, the leſs is the force of the ſun's attraction upon it. And, therefore, thoſe planets which are the nearer to the ſun muſt move the faſter in their orbits, in order thereby to acquire centrifugal forces equal to the power of the ſun's attraction: and thoſe which are the farther from the ſun muſt move the ſlower, in order that they may not have too great a degree of centrifugal force, for the weaker attraction of the ſun at thoſe diſtances.

*E.* Then I underſtand, that the ſun's attraction, at each particular planet, is equal to the centrifugal force of each planet; and, by that means, the planets are all retained in their reſpective orbits. Is it not ſo?

*N.* Accurately ſo.

*E.* Then, as the power of the Deity is manifeſt, in having ſet off ſuch large bodies as the planets are, with ſuch amazing degrees of velocity; ſo his great wiſdom is conſpicuous, in having ſo exactly adjuſted their velocities, and, conſequently, their centrifugal forces, to the different degrees of the ſun's attraction at the diſtances the planets are from him.——Here is a wonderful balance indeed! Can there be an atheiſt?—I am ſure no man could be ſo, after hearing ſuch things as you have told me of.

*N.* 'Tis ſaid there are atheiſts; but they muſt all be ſtupid fools.——The Almighty has laid the great book of nature open to our view; ſo that, every one that runs may read. Suppoſing matter had exiſted from eternity, (which, by the bye, is too great a compliment to be paid to matter) I imagine, the greateſt atheiſt in the world could hardly bring himſelf to believe, that ſtones could have hewed themſelves, bricks made themſelves, trees ſhaped themſelves into beams and boards, and mortar made itſelf; and then, all theſe materials have jumbled themſelves together, ſo as to build a houſe. And what is a houſe in compariſon to a planetary ſyſtem; or



Pl. II.

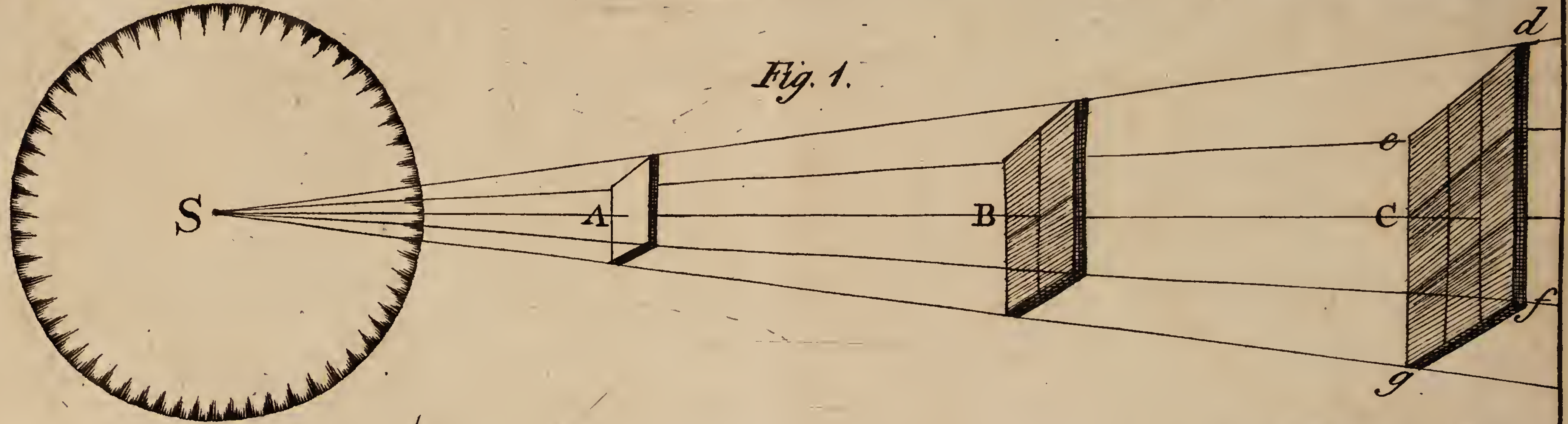


Fig. 1.

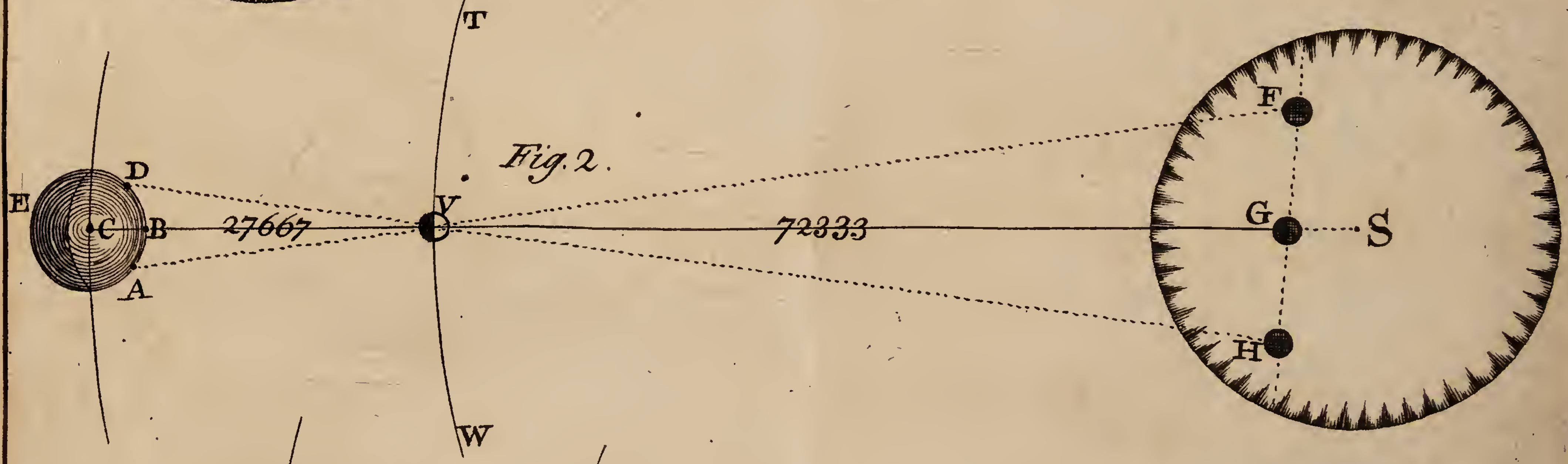


Fig. 2.

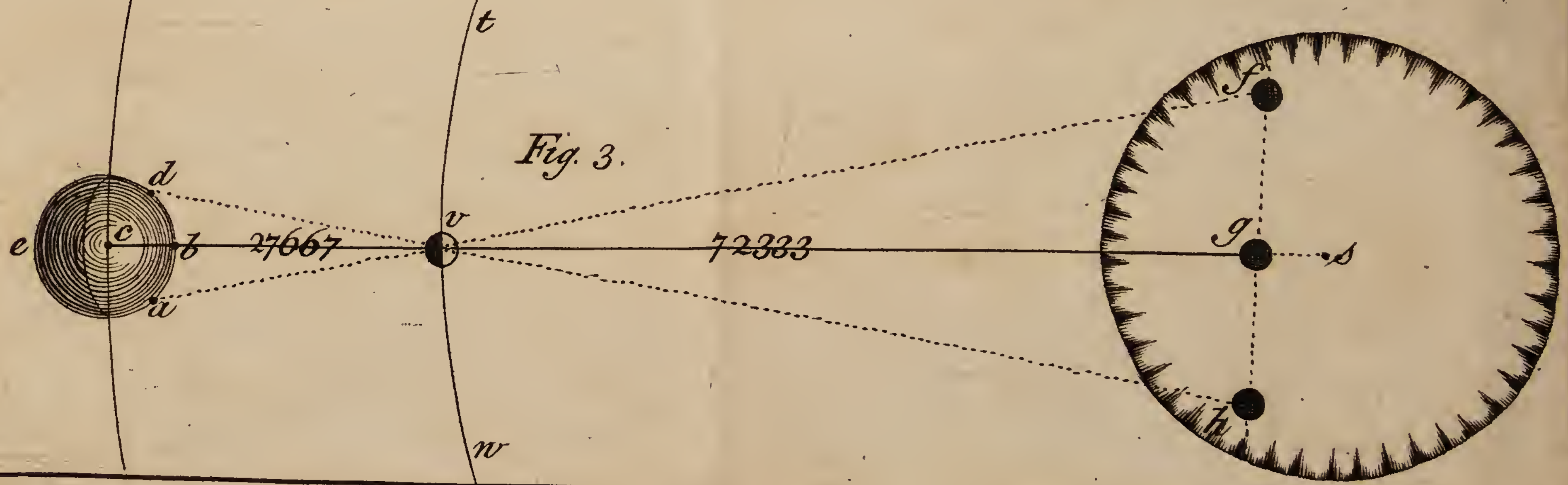


Fig. 3.

or the ſkill required to build it, when compared with the organization of any inſect?

*E.* Nothing at all.——But I am apt to lead you into digreſſions. Doth the power of the ſun's attraction decreaſe in proportion as the diſtance from him increaſes?

*N.* No: his attractive force diminiſhes in proportion as the ſquares of the diſtances (that is, as the diſtances multiplied by themſelves) from him increaſe. So that, at twice the diſtance from the ſun's center, his attractive force is four times leſs; at thrice the diſtance, it is three times three times, or nine times leſs; at four times the diſtance, the attraction is four times four times, or ſixteen times leſs; and ſo on.—And this we find, from the comparative diſtances of the planets from the ſun, and their different velocities in their orbits: beſides, I have often ſeen this experimentally confirmed by a machine called *The whirling-table.*

*E.* If I underſtand this; ſuppoſing there are four planets ſo placed, as that the diſtance of the ſecond from the ſun is twice as great as the diſtance of the firſt; the diſtance of the third, three times as great; and the diſtance of the fourth, four times as great as the diſtance of the firſt: the fourth will be attracted only with a ſixteenth part of the force wherewith the firſt is attracted; the third only with a ninth part of the force; and the ſecond with only a fourth part of the force that attracts the firſt.

*N.* Exactly ſo.

*E.* I ſhould be glad to know the reaſon why the ſun's attraction decreaſes in proportion to the ſquares of the diſtances from him. Why do you ſhake your head?

*N.* Becauſe you aſk me a queſtion which Sir Iſaac Newton himſelf could not ſolve; although he was the prince of philoſophers.

*E*. But can you give me no idea at all of it?

*N*. I could; and a very plain one too, if the attractive force (the effect of which we call gravity) acted only according to the ſurface of the attracted body.

*E*. Your *if* implies that it does not: but, if it did, why ſhould it decreaſe in that proportion?

*N*. I have drawn a figure for your inſpection (PLATE II. *Fig*. 1.) which indeed is for a quite different purpoſe: but it would exactly ſolve your queſtion, if gravity acted as all mechanical cauſes do; only on the ſurfaces of bodies.

Let *S* be the center of the ſun; and *S d*, *S e*, *S f*, *S g*, be, as it were, lines of attractive force, drawing the three ſquare plates *A*, *B*, and *C*, toward *S*. Theſe lines touch only the four corners of the plates; but we may ſuppoſe the whole ſpace within them to be full of ſuch attractive lines, laying hold of all the parts, or points (if you will) of the ſurface of each plate: and every particle of matter in each plate requiring an equal degree of power to draw it equally faſt toward the ſun.

Now, let the plate *B* be twice as far from the ſun's center as the plate *A* is; the plate *C* three times as far, and the attractive forces equal on each plate, as if the above mentioned four lines *S d*, *S e*, *S f*, and *S g*, were four cords, equally ſtretched, and pulling all the plates with equal forces toward *S*.——But, the plate *B* being twice as long, and twice as broad as the plate *A*, it is plain, by the figure, that *B* contains four times as much ſurface as *A* does, and four times as great a quantity of matter, ſuppoſing it as thick as *A*; and the plate *C*, being three times as broad and three times as long as *A*, contains nine times as much ſurface and matter as *A* does, ſuppoſing it of an equal thickneſs with *A*.

Suppoſe now, that the intermediate lines of attraction, between the four corner lines, are ſo cloſe together, as that they lay hold of every point of the ſurface of *A*, and draw it toward *S* with all their force: it is plain, that they can only lay hold of every fourth point of the ſurface of *B*, and of every ninth point of the ſurface of *C*; ſo that, the plate *B* will want three fourth parts of the attraction that would be ſufficient to draw it toward *S* as faſt as the plate *A* is drawn; and *C* will want eight ninth parts of the attraction that would be ſufficient to make it move as faſt as *A* moves toward *S*.

*E*. I ſee this very well: but, if gravity acts not according to the quantity of ſurface, pray how does it act?

*N*. Exactly in proportion to the ſolid contents of bodies; that is, to the quantities of matter they contain. For, you know, that if you would take the plate *C* as it is, and weigh it in a balance; then take it out, and cut it in the lines drawn on its ſurface, by which means you would divide it into nine ſquare pieces: if you then lay them above one another in the ſcale, they will be juſt as heavy as they were before, when they lay at each other's edges, all in one piece, in the ſcale. Or, if you ſuppoſe them to be ſo cut, and then joined together at each other's backs, and put them at the diſtance *S c* from the ſun, as before; they will have only a ninth part of the ſurface toward the ſun as before: and yet, the ſun's attractive force on them will be juſt the ſame.

*E*. Then, it ſeems, there is no way of accounting for the manner in which gravity acts, but by reſolving it into the will of the Deity; ſeeing that the quantity of ſurface has nothing to do in the caſe.

*N*. Indeed there is not. And, therefore, when I henceforth ſpeak of gravity, I would have you always underſtand, that I do not thereby mean a *Cauſe*, but the *effect* of a cauſe, which we do not comprehend. Beſides, you know, that if gravity acted according to the ſurfaces, or bulks of bodies, a cork would be as heavy as a piece of lead of the ſame bulk as the cork.

*E.* Very true.——But as you told me that the figure we have been looking at, was not intended to ſhew how gravity acts; may I enquire what you intend to teach me by it; as you ſaid you drew it for me?

*N.* It is to ſhew, that the light of the ſun, or of any other luminous body, decreaſes in proportion as the ſquare of the diſtance from the luminous body increaſes. The rays of the ſun's light go out in ſtraight lines from all points of the ſun's ſurface: and, conſequently, the farther they go off from the ſun, the more they ſpread; and ſo they cover the more of the ſurfaces of bodies at the greater diſtances.

*E.* How is it known that light moves in ſtraight lines?

*N.* Becauſe, if we endeavour to look at the ſun, or at a candle, through the bore of a bended pipe, we cannot ſee it; but through a ſtraight pipe we can.

*E.* Enough, Brother; pleaſe now to explain the figure.

*N.* Let *S* be the ſun's center, and *S d*, *S e*, *S f*, *S g*, be four rays of light, going out from the ſun's ſurface in ſtraight lines (in the ſame direction as if they proceeded from his center), and ſuppoſe the ſpace within theſe rays to be filled with others. Take the diſtances *S A*, *S B*, *S C*, from the ſun's center, ſo as *S B* ſhall be twice as great as *S A*, and *S C* thrice as great. Then, at the diſtance *S A* place the little ſquare plate *A*, on which all the rays will fall that fill the above-mentioned ſpace at *A*. At the diſtance *S B*, place the ſquare plate *B*; which being twice as long and twice as broad as the plate *A*, it contains four times as much ſurface as *A* does: and if *A* be taken away, all the light that fell upon it, will fall upon, and cover the whole ſurface of *B*; which being four times as large in ſurface as *A* is, and having only as much light upon it as *A* had, every point of the ſurface of *B* can have no more than a fourth part of the light that fell upon every point of the ſurface of *A*. And, laſtly, at three times the diſtance *S A*, place the ſquare plate *C*; which being three times as long and three times as broad as the plate *A*, it contains nine times as great a ſurface: and then, if *B* be taken out of the way, ſo as to let all the light that fell upon it go on to the plate *C*, the light will juſt cover the ſurface of that plate; which being nine times as large as the ſurface of *A*, and having no more light upon it than *A* had, 'tis plain, that the light upon every point of *C* is but a ninth part ſo ſtrong and vivid as it was upon every point of *A*.

*E.* Nothing can be plainer than this: and it follows of courſe, that at four times the diſtance of *A* from the ſun, his light is ſixteen times weaker than at *A*; at five times the diſtance, it is twenty-five times weaker; and ſo on. I thank you for making this ſo plain.

*N.* Indeed I deſerve none of your thanks for it. I copied the figure from Doctor Smith's Optics. That worthy gentleman was my good old maſter; and he is maſter of Trinity College in Cambridge.

*E.* Seeing that the comparative diſtances of all the planets from the ſun are known, I make no doubt but you can tell me, what the comparative quantities of the ſun's light on all the planets are.

*N.* Very eaſily.—The ſun's light is ſeven times as great on Mercury as on the Earth; about twice as great at Venus; at Mars, it is not half ſo great, or ſtrong, as we have it on the Earth; at Jupiter, only a twenty-eight part ſo ſtrong as at the Earth; and at Saturn, is but about a ninetieth part ſo ſtrong as with us.

*E.* Then, I ſhould be almoſt tempted to think,—but I cannot—will not indulge ſuch a thought as that the Deity is partial: for I cannot imagine the inhabitants of our earth to be better than thoſe of the other planets. On the contrary, I would fain hope they have not acted ſo abſurdly with reſpect to him, as we have done.

*N.* Tell me freely what the thought was that aroſe in your mind, which you are ſo willing to ſuppreſs.—The Deity is no other way a reſpecter of perſons than that of properly diſtinguiſhing between the good and the bad; and ſo rewarding the one, and puniſhing the other accordingly.

*E.* It ſeemed to me, that the inhabitants of the neareſt planets to the ſun muſt be blinded by too much light; and that thoſe of the fartheſt planets from the ſun muſt be puniſhed all their lives, with ſo weak a light, as can be called little better than darkneſs.—We could not bear ſeven times as much light as we have from the ſun; nor be able to do our work with only a ninetieth part of the light we have.

*N.* Your reflection, ſiſter, is very natural. But, after aſking you two or three plain queſtions, I believe I ſhall be able to give you full ſatisfaction on that head.

*E.* Pray aſk them, and I will anſwer them if I can.

*N.* After you have been a while out in the ſnowy ſtreet, can you ſee as well to work with your needle immediately on coming into your room, as you did before you went out?

*E.* No.

*N.* Can you bear the ſtrong reflection of the ſun's light from the ſnow, juſt as well when you go out into the ſtreet, as when you have been walking half an hour in it?

*E.* No.

*N.* Can you give ſuch a reaſon for this as would ſatisfy a philoſopher ? For you know that the ſnow reflects not leſs light for you having been a while walking in it ; nor is your room a bit the darker for your having been out of it.

*E.* I wiſh I could, but indeed I cannot.

*N.* Then I will tell you.——Our eyes are made ſo, that their pupils (which let in the light, whereby we ſee objects) dilate when the light is weak, that they may take in the more of it ; and contract when the light is ſtrong, that they may admit the fewer of its rays.——Whilſt you are in your room, the pupils of your eyes are dilated ; and for that reaſon, when you go out, they take in too much of the light reflected from the ſnow, which you find is hurtful. But they ſoon contract ſo, as to admit no more of that ſtrong light than you can eaſily bear.——And then, when you come into your room, with the pupils of your eyes contracted ; the room, being not ſo light as the ſtreet, appears darker to you than it did before you went out : but, in a ſhort time, the pupils dilate again ; and then they let in a ſufficient quantity of light for you to work by.

Now, ſuppoſing all the other planets to be inhabited by ſuch beings as we are, (though for reaſons I ſhall mention afterwards, we cannnot believe they are), if the pupils of their eyes who live on the planet Mercury are ſeven times as ſmall as ours are, the light will appear no ſtronger to them there than it doth to us here. And if the pupils of their eyes who live on Saturn are ninety times as large as ours, (which they will be, if they are nine times and an half as large in diameter as ours ; and which will appear to be no deformity where all are alike, and other ſorts have never been ſeen) the light there will be of the ſame ſtrength as it is to our eyes here.——Pray, *Eudoſia,*

*ſia*, how many full moons, do you think, would there need to be placed in a clear ſky, to afford us moon-light equal to common day-light, when the ſun doth not ſhine out, and all our light is by reflection from the clouds?

*E.* Indeed I cannot tell :——but am apt to think, that ſixty, or an hundred, at moſt, would do. For, when the full moon is not clouded, ſhe ſhines ſo clear, that I can read by her light.

*N.* Sixty, or an hundred : I aſſure you, that you are greatly miſtaken : for it would require ninety thouſand : and *that* number would fill the whole of our viſible ſky.

*E.* You amaze me! but I know you will not deceive me. Pray, how can you find any method of comparing moon-light with day-light, ſo as to aſcertain the great difference between the quantities thereof?

*N.* Have you never obſerved the moon pretty high up in the morning, after the ſun was riſen, when the moon was about three quarters old?

*E.* Yes, brother : and when I have ſeen her, as it were, among whitiſh clouds, ſhe appeared much of the ſame colour as they did ; very dim in compariſon with what ſhe appears in the night.

*N.* And yet, ſhe was juſt as bright then as ſhe is in the night ; only the ſuperior light of the day made her ſeem ſo much otherwiſe. Like a candle, which appears very bright in the night-time ; but ſet it in the ſtreet in day-light, and it will ſeem very dim, although its real brightneſs is ſtill the ſame.

*E.* I think I could almoſt tell what you are to infer from all this ; but will not ſpeak, leſt I ſhould be miſtaken again. And therefore I beg you will proceed.

*N.* When the ſun is hid by clouds, all the light we have is by reflection from them. The moon reflects the ſun's light in the night-time, as the clouds do in the day: and as ſhe can reflect no more light in the day than a ſmall bit of a whitiſh cloud does, that covers as much of the ſky as the moon covers; ſhe can reflect no more in the night.——And as the full moon fills only a ninety-thouſandth part of the ſky, her light is no more than equal to a ninety-thouſandth part of common day-light. Now, as the light of the ſun at Saturn is equal to a ninetieth part of his light at the earth, and common day-light at the earth is 90,000 times as great as moon-light; divide 90,000 by 90, and the quotient will be 1000; which ſhews, that the ſun's light at Saturn is 1000 times as great as the light of the full moon is to us.

*E.* I ſee plainly that it muſt be ſo——Oh!——

*N.* Why do you ſigh, *Eudoſia?*

*E.* Becauſe there is not an univerſity for ladies as well as for gentlemen. Why, *Neander*, ſhould our ſex be kept in total ignorance of any ſcience, which would make us as much better than we are, as it would make us wiſer?

*N.* You are far from being ſingular in this reſpect. I have the pleaſure of being acquainted with many ladies who think as you do. But if fathers would do juſtice to their daughters, brothers to their ſiſters, and huſbands to their wives, there would be no occaſion for an univerſity for the ladies; becauſe, if thoſe could not inſtruct theſe themſelves, they might find others who could. And the conſequence would be, that the ladies would have a rational way of ſpending their time at home, and would have no taſte for the too common and expenſive ways of murdering it, by going abroad to card-tables, balls, and plays: and then, how much better wives, mothers, and miſtreſſes they would be, is obvious to the common ſenſe of mankind.——The misfortune is, there are but few men who know theſe things: and where that is the caſe, they think the ladies have no buſineſs with them; and very abſurdly imagine becauſe they know nothing of ſcience themſelves, that it is beyond the reach of women's capacities.

*E.* But, is there no danger of our ſex's becoming too vain and proud, if they underſtood theſe things as well as you do?

*N.* I am ſurpriſed to hear you talk ſo oddly.——Have you forgot what you told me two days ago; namely, that if you had been proud before, the knowledge of Aſtronomy, you believed, would make you humble?

*E.* You have caught me napping, as the ſaying is:——but I will not take up more of your time at preſent with digreſſions. I remember this morning, to have heard you mention the light's *going* from one place to another, as if it took ſome time in moving through open ſpace. I know that ſound does ſo; becauſe I have ſeen the flaſh of a diſtant cannon before I heard the noiſe that it made.

*N.* True, ſiſter; and you did not ſee the flaſh at the very inſtant when it was given, though you ſaw it very ſoon after.

*E.* And do you know with what degree of ſwiftneſs light moves?

*N.* Yes; and you ſhall ſoon know too. The Earth's orbit lies far within the orbit of Jupiter.

*E.* Undoubtedly; becauſe Jupiter is much farther from the ſun than the Earth is.

*N.* Then you know that when the Earth is between Jupiter and the Sun, the Sun and Jupiter appear oppoſite to each other in the heavens. And when the Sun is nearly between us and Jupiter, the Sun and

Jupiter appear nearly in the ſame part of the heavens.

*E.* Undoubtedly they muſt.

*N.* And therefore, when the Sun and Jupiter appear almoſt cloſe together, the Earth is almoſt the whole diameter of its orbit farther from Jupiter, than when it and Jupiter appear oppoſite to each other in the heavens.

*E.* Certainly.

*N.* The times when Jupiter's moons muſt be eclipſed in his ſhadow are eaſily calculated; becauſe, by teleſcopic obſervations, the times in which they go round him are accurately known: and the apparent vaniſhing of theſe moons in the ſhadow may be very well perceived through a teleſcope; or the inſtants when they recover their light again, by the ſun's ſhining upon them, at their going out of the ſhadow. And it has been always obſerved, ſince teleſcopes were invented, that theſe eclipſes are ſeen ſixteen minutes ſooner when the Earth is neareſt to Jupiter, than when it is fartheſt from him. So that, if there were two Earths moving round the ſun in the ſame orbit, and always keeping oppoſite to each other; when one of them is at its leaſt diſtance from Jupiter, and the other at its greateſt, an obſerver on the neareſt would ſee the ſame eclipſe ſixteen minutes ſooner than an obſerver on the fartheſt would. Which ſhews, that light takes ſixteen minutes to move through a ſpace equal to the width or diameter of the Earth's orbit, which is 190 millions of miles. And, conſequently, it muſt take eight minutes of time in coming from the ſun to the earth: as the ſun is nearly in the center of the earth's orbit: that is, at the half of 190 millions of miles, or 95 millions of miles from the earth.

*E.* I underſtand this; but a difficulty riſes in my mind.

*N.* Only mention it, and I will remove it if I can.

*E.* The rays of the ſun's light come directly from him to the Earth; but his rays from Jupiter's moons come to us only by reflection. Are you ſure that reflected light moves with the ſame velocity that direct light does?

*N.* There is no reaſon to believe but that it does. And I imagine, I can very eaſily convince you that it does ſo.

If the particles of light did not fly off from the planets as faſt as they came upon them, there would ſtill be an accumulation of light upon them; which would make them appear every night brighter and brighter; but, in reality, they do not. And if the light flew off faſter from the planets than it comes upon them, they would appear dimmer and dimmer every night; which is not at all the caſe.

*E.* But are *all* the rays which the ſun darts on any planet *reflected* from it, and none of them loſt or *abſorbed* in the matter of which the planet is compoſed? Or, if *ſome* of them be abſorbed, will not this invalidate your argument?

*N.* Not at all, if the *abſorbed* rays bear a conſtant proportion to the *whole* number of rays with which the planet is ſucceſſively illuminated; and this muſt undoubtedly be the caſe: for the ſame parts of the planet's ſurface which either reflect, or abſorb the rays that fall upon them *this* moment, will be equally diſpoſed to reflect or abſorb the rays that fall upon them in the *next*: and ſo the *ſame proportion* between the abſorbed and reflected rays, or between them and the whole quantity of light thrown on the planet, will be continually preſerved.

*E.* But what if ſome parts of the planet's ſurface be more hardened by drought, or ſoftened by wet, as on our earth; or be in any other reſpect more diſpoſed, either to reflect, or abſorb the Sun's rays at ſome times than at others; would not this vary the proportion you have mentioned?

*N.* If we may judge of this from our own globe, where the contrary qualities of drought and wet, hardneſs and ſoftneſs, ſmoothneſs and roughneſs of ſome parts of its ſurface, ſo far as they reſult from any alteration of *weather*, &c. if taken upon an average for a whole year, or other given time, and throughout any half of the Earth's ſurface; they will, very nearly, if not exactly, balance each other. The ſame may be therefore ſuppoſed to hold good in the other planetary worlds; and ſo the proportion before mentioned will not be ſenſibly altered.

*E.* You have quite removed my difficulty, brother; and I thank you for having done it. But, as light comes from the Sun to the Earth in eight minutes of time, its ſwiftneſs muſt be amazingly great. Let me try whether I can compute it: for you taught me not only the four common rules of arithmetic before you went to the univerſity, but even the rule of three. The Sun's diſtance from the Earth is 95 millions of miles, in round numbers; and light moves through that ſpace in 8 minutes of time; divide, therefore, 95,000,000 by 8, and the quotient is 11,875,000, for the number of miles that light moves in a minute. Now I remember that you told me, a cannon ball moves at the rate of 480 miles in an hour, which is 8 miles in a minute; I therefore divide 11,875,000 by 8, and the quotient is 1,484,375; ſo that light moves more than a million of times as ſwift as a cannon-ball.——Amazing indeed!

*N.* It is ſo:——And now I will tell you ſomething which is full as amazing.

*E.* What can that be: do you mean the power of the Almighty?

*N.* Far from it: I only mean the inconceiveable ſmallneſs of the particles of light.

*E.* And how do you know that they are ſo inconceiveable ſmall?

*N.* The force with which a body ſtrikes any obſtacle, is directly in proportion to the quantity of matter in the body, multiplied by the velocity with which it moves. And conſequently, as the volocity of light is, in round numbers, a million of times as great as the velocity of a cannon-bullet; if a million of the particles of light were but as big as a common grain of ſand, we could no more keep our eyes open to bear the impulſe of light, than we could to have ſand ſhot point blank againſt them from a great cannon.

Another way of proving that the particles of light are ſo ſmall as to exceed all human comprehenſion, is this: Let a lighted candle be ſet on the top of a ſpire ſteeple, in the night-time, and there will be a very large ſpherical ſpace filled with the light of the candle before a grain of the tallow be conſumed; and as *that* grain of tallow is divided into ſo many particles, as fill all the ſpace in which the light is diffuſed, can you poſſibly imagine how ſmall the particles are into which it is ſo divided?

*E.* Indeed I can form no idea thereof.

*N.* A very good computiſt has found, that the particles of blood of thoſe animals which can only be ſeen by means of a microſcope, are as much ſmaller than a globe whoſe diameter is only a tenth part of an inch, as that ſmall globe is leſs than the whole earth. And yet, that their particles of blood are like mountains to a grain of ſand, when compared with the particles of light.

*E.* I am glad to hear our breakfaſt-bell: —for, if I ſhould hear more of theſe ſubjects at preſent, I know not but that I ſhould, for ſome time, loſe the power of thinking.

*N.* I had juſt done with the ſubject of light; but am ſorry to hear that you muſt go from home, for a few days, on a viſit. However, during your abſence, I intend to draw out two or three figures, in order to deſcribe the late tranſit of Venus to you by them; and give you ſome idea of the method by which the diſtances of the planets from the Sun were found, by obſervations made on that tranſit.

*E.* I am very much obliged to you, Sir, for the trouble you have taken, and are to take further, on my account: and ſhall return as ſoon as poſſible.—You know I could not refuſe Miſs *Goodall*'s invitation.

* * *

Pl. III.

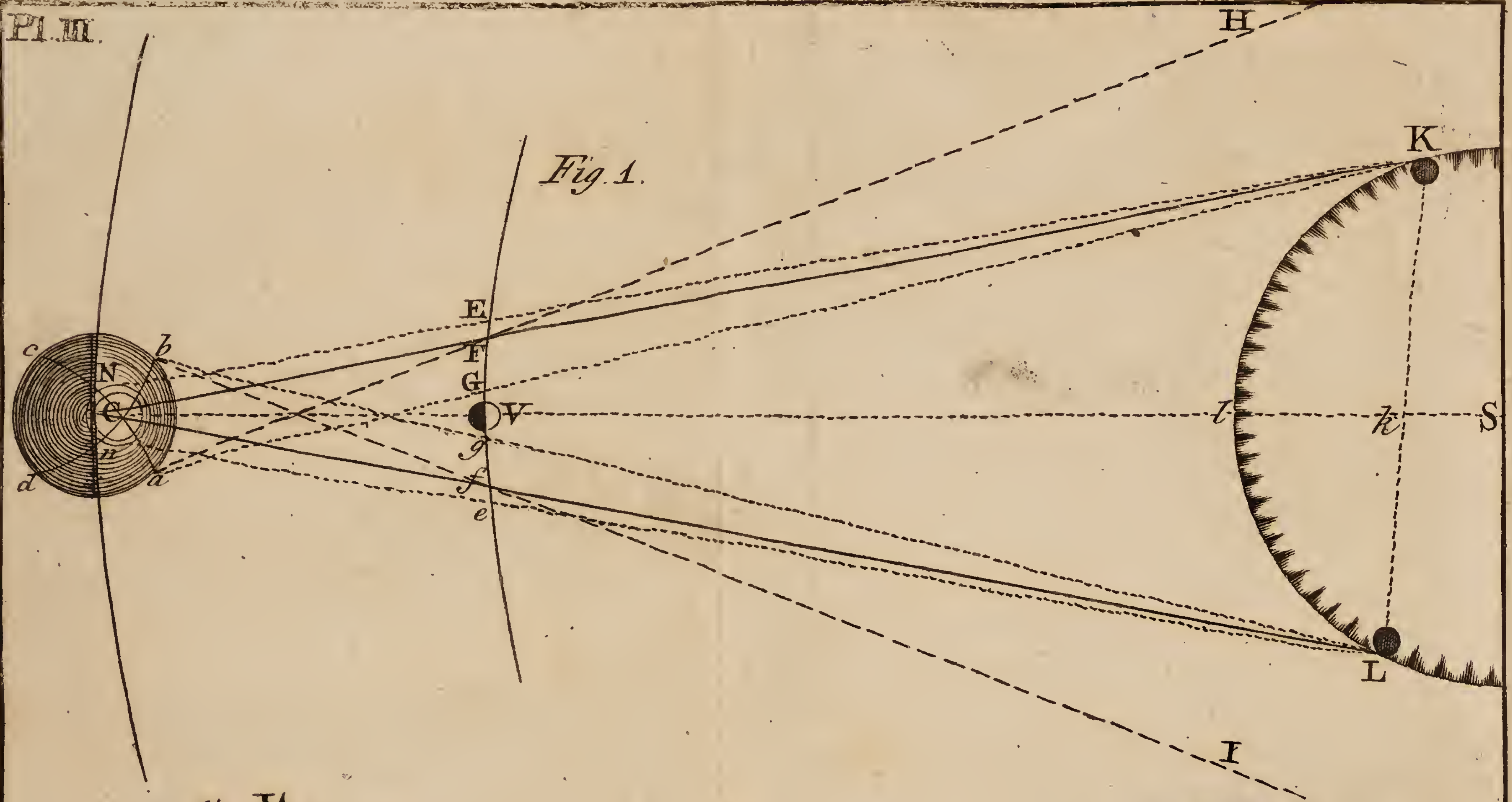


Fig. 1.
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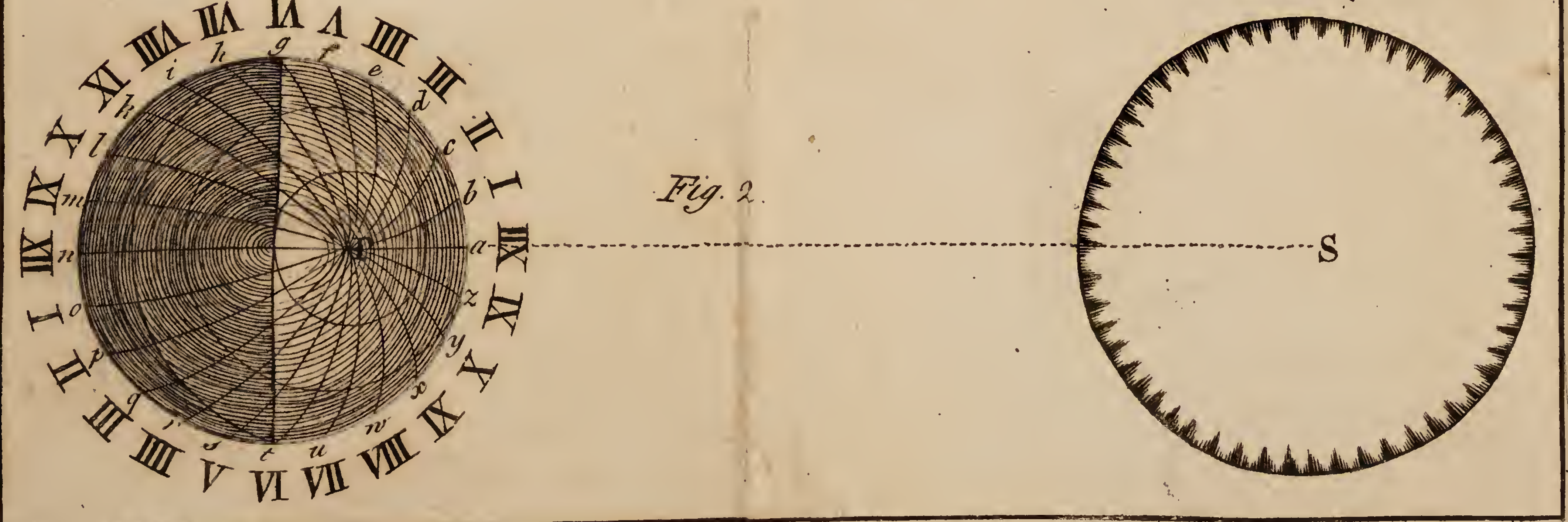
Fig. 2.
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# DIALOGUE IV.

*On the Tranſit of* VENUS, *June 6th,* 1761; *and how the diſtances of the* PLANETS *from the* SUN *were found thereby.*

*Neander.*

DEAR Siſter, I am very glad to ſee you again: I ſuppoſe you found Mr. and Mrs. *Goodall*, and their daughters, to be very agreeable company.

*Eudoſia.* Quite ſo, and I have ſpent three days very happily with them.

*N.* It was very obliging in Mr. *Goodall* and Miſs *Sophy* to ſee you ſafe home.

*E.* They would do it, for all that I could ſay: even though I told them, that the ſervant who was ſent for me was very careful.

*N.* Mr. *Goodall* and I ſpent an hour together laſt night: and though he was full of his praiſes of your good ſenſe, he did not ſay one word about our aſtronomical converſations; by which, I imagine, you ſpoke nothing about them in that family. Yet I am far from doubting, that it would have been very agreeable if you had.

*E.* Truly, brother, if I had, you muſt have heard of it : and then I ſhould not have wondered if you had ſaid that I am not over-ſtocked with good ſenſe. I muſt know theſe things better before I begin to ſpeak of them; and even then, not to ſpeak, unleſs I am deſired by thoſe to whom I think the ſubject will be entertaining. You told me, the morning I went away, that our next converſation ſhould be on the tranſit of Venus ; and how the diſtances of the planets from the Sun were found thereby.

*N.* And to ſhew you that I have not forgot my promiſe, here are the figures which I told you I would draw out for that purpoſe. [See PLATE II. *Fig.* 2. *and* 3. *and* PLATE III. *Fig.* 1.] But, in theſe delineations, we muſt often ſacrifice one truth to explain another : and in the preſent caſe it is unavoidable. For, if we were to make the bulks of the planets in our figure no greater than they are in proportion to their diſtances from the Sun, the planets would be mere points ; and a large ſheet of paper would be too ſmall for the lengths of the lines of diſtances. So that, in order to make the preſent ſubject plain, we muſt enlarge the planets, and contract their diſtances from the Sun ; otherwiſe, we could not, at preſent, render the effects intelligible which ariſe from ſome of the planetary motions.

*E.* Very well, brother : pleaſe to proceed.

*N.* The diameter of the Earth is no more than a point in compariſon of its diſtance from the Sun ; and therefore, if the Sun were viewed, at the ſame inſtant, by two obſervers on oppoſite ſides of the Earth, his center would appear to both of them to be in the ſame point of the heavens. But, when Venus is between the Earth and the Sun, (as ſhe was at the time of her late tranſit)

ſit) her diſtance from the Earth is between three and four times leſs than the Sun's diſtance from the Earth. And therefore, if Venus be then viewed by two obſervers on the Earth, who are at a great diſtance from one another, ſhe will appear to each of them, at the ſame inſtant, to be on different parts of the Sun's ſurface.— Thus, in *Fig.* 2. of PLATE II. let *S* be the Sun, *V* Venus, and *A B D E* the Earth. Let one obſerver be at *A*, another at *B*, and a third at *D*; all looking at Venus at the ſame moment of abſolute time. To the obſerver at *A*, Venus (*V*) will appear upon the Sun at *F*, as ſhe is ſeen in the right line *A V F*: to the obſerver at *B*, ſhe will appear upon the Sun at *G*, being ſeen by him in the right line *B V G*: and to the obſerver at *D*, Venus will appear upon the Sun at *H*, becauſe he ſees the planet in the right line *D V H*. Or, if you will ſuppoſe Venus to be at reſt at *V*, during the time that the obſerver at *A* is carried, by the Earth's motion on its axis, from *A* to *D*, through the arc *ABD*; 'tis plain, that, to this obſerver, the planet *V* will appear to have moved on the Sun from *F* to *H*, through the ſpace *F G H*.

Let us now ſuppoſe, that the Earth *a b d e Fig.* 3.) is nearer the Sun *s* than as repreſented in *Fig.* 2. in which caſe, Venus *v* will be proportionably nearer the Earth; and the arc *a b d*, through which the obſerver is carried, will bear a greater proportion to the diſtance of Venus *v* from the Earth, in *Fig.* 3. than the ſame arc *AB D* (in *Fig.* 2.) bears to the diſtance of Venus *V* from the Earth. So that, if one obſerver ſhould be placed at *a*, another at *b*, and a third at *c*, the oberver at *a* would ſee Venus on the Sun at *f*, the obſerver at *b* would ſee her on the Sun at *g*, and the obſerver at *d* would ſee her on the Sun at *h*, all at the ſame inſtant of time. Or, if Venus kept at reſt at *v*, whilſt the obſerver at *a* was carried from *a* to *d* by the Earth's motion; Venus would, in that time, appear to him to have moved from *f* to *h* on the Sun. But the ſpace *f g h*, in *Fig.* 3. is longer than the ſpace *F G H* in *Fig.* 2. and therefore, the nearer the Earth is to the Sun, the greater will the ſpace be through which Venus appears to move upon the Sun, by the obſerver's real motion along with the Earth, in any given time; and the farther the Earth is from the Sun, the leſs will the ſpace be through which Venus appears to move upon the Sun, by the obſerver's real motion, in the ſame time.

And, conſequently, as Venus is really moving on in her orbit, in the direction of *T V W*, (in *Fig.* 2.) or *t v w* (in *Fig.* 3.) whilſt the obſerver is carried by the Earth's motion on its axis from *A* to *D*, or from *a* to *d*; 'tis plain, that Venus will appear to move ſooner over the Sun, if the Earth's diſtance from the Sun be only *b v s*, (as in *Fig.* 3.) than if it be *B V S*, (as in *Fig.* 2.) So that, the whole duration of her tranſit over the Sun muſt be ſhorter, if the Earth's diſtance from the Sun be only *b v s*, than if it be greater, as *B V S*.——Do you underſtand this, *Eudoſia?*

*E.* I think it is ſo plain, that any body might underſtand it.

*N.* Then, we have done with theſe figures, and ſhall proceed to *Fig.* 1. of PLATE III, in which, let *a b c d a* be the Earth, *V* Venus, and *S* the Sun. The Earth turns eaſtward on its axis, in the direction *a b c d*; and Venus moves in her orbit in the direction *E V e*.

Now, ſuppoſe the Earth to be tranſparent like glaſs, and that you were placed at its center *C*, and kept looking at the Sun *S*, during the time in which Venus moves in her orbit from *F* to *f*, through the ſpace *F G V g f*: in this caſe, the Earth's motion on its axis would have no effect on your poſition, becauſe it could not carry you any way from *C*. Then, when Venus was at *F* in her orbit, ſhe would appear to you as at *K*, juſt within the Sun's ſurface, touching his eaſtern edge at *K*; that is, at her firſt internal contact with the Sun's eaſtern edge. As ſhe moves on, from *F* to *f* in her orbit, ſhe would appear to you to move on the Sun, from *K* to *L*, in the line *K k L*, which is called *the line of her tranſit over the Sun.* And when ſhe was at *f* in her orbit, ſhe would appear at *L* on the Sun, juſt beginning to leave his weſtern edge, or at her laſt internal contact with the Sun. Now, pleaſe to remember, that if Venus could be ſeen from the Earth's center *C*, ſhe would move from *F* to *f* in her orbit, in the time that ſhe would appear to move from *K* to *L* on the Sun; or from her firſt internal contact to her laſt.

*E.* A bare inſpection of the figure ſhews it: for, when Venus is at *F* in her orbit, ſhe would appear juſt within the Sun at *K*; becauſe then, as viewed from the Earth's center *C*, ſhe would be ſeen in the ſtraight line *C F K*; and when ſhe came to *f* in her orbit, ſhe would ſeem juſt beginning to leave the Sun at *L*, becauſe ſhe would be ſeen in the ſtraight line *C f L*.

*N.* Very well.—Now let us ſuppoſe, that an obſerver is placed on the Earth's ſurface at *a*; and that he is carried from *a* to *b*, by the Earth's motion on its axis, in the time that Venus moves in her orbit from *F* to *f*.

When Venus is at *F*, ſhe appears at *K* on the Sun, as ſeen from the Earth's center *C*; but to the obſerver at *a* ſhe will not appear to be then entered upon the Sun; becauſe (if ſhe were then viſible in the ſky) ſhe would be ſeen in the line *A F H*, eaſtward from the Sun; and muſt move on from *F* to *G* in her orbit, before the obſerver at *a* can ſee her on the Sun at *K*, in the right line *a G K*. So that her tranſit will begin as much later to the obſerver at *a*, than it does to the obſerver at *C*, as ſhe is in moving from *F* to *G* in her orbit.

When Venus comes to *g* in her orbit, the obſerver will be carried by the Earth's motion almoſt from *a b*;

and then he will ſee her in the line *c f L*, juſt beginning to leave the Sun at *L*; but ſhe muſt move on from *g* to *f* in her orbit, before ſhe begins to leave the Sun at *L*, as ſeen from the Earth's center *C*, in the right (or ſtraight) line *C f L*; and then, to the obſerver at *b*, ſhe will appear quite clear of the Sun to the Weſt, in the line *B f I*. So that the whole duration of the tranſit from *K* to *L* on the Sun, will be ſhorter, as ſeen by the obſerver in motion from *a* to *c*, than as ſeen by the (ſuppoſed) obſerver at reſt at the Earth's center *C*. For, to the former, ſhe will move only from *G* to *g* in her orbit, during the time ſhe appears to move from *K* to *L* on the Sun: whereas, to the latter, ſhe muſt move from *F* to *f* in her orbit, in the time ſhe appears to paſs over the Sun from *K* to *L*.

The nearer the Earth is to the Sun, the greater will the difference of the durations of the tranſit be, from *K* to *L* on the Sun, as ſeen from the Earth's ſurface and from its center: and the farther the Earth is from the Sun, the leſs will the difference between the durations of the tranſit be, as ſeen from the Earth's ſurface and from its center, accordingly.

*E*. Certainly ſo, by what you already told me in your explanation of the ſecond and third figures of the ſecond *Plate*. For, the nearer the Earth is to the Sun, the nearer alſo, in proportion, it muſt be to Venus, and the farther it is from the Sun, the farther alſo it muſt be from Venus. So that the ſpace through which the obſerver is carried by the Earth's motion, from *a* to *b*, (PLATE III. *Fig*. 1.) will bear a greater proportion to the diſtance of Venus from the Earth in the former caſe than in the latter: and ſo, will affect the times of durations of the tranſit, as ſeen from the Earth's center and from its ſurface, accordingly.——But I ſhould be glad to know, why you ſuppoſe an obſerver to be placed at the Earth's center,

ter, as it is a thing impoſſible to be done: and if he was there, he could neither ſee the Sun nor Venus.

*N.* Becauſe the motions of the planets are calculated in the aſtronomical tables, as if ſeen by an obſerver at reſt. And as the apparent breadth of the Sun is known, and the time of Venus's going round the Sun is alſo known; the time of her appearing to move through a ſpace equal to the Sun's breadth, as ſeen by an obſerver at reſt, is eaſily calculated, and is the ſame as would be obſerved by a perſon placed at reſt at the center of the Earth. And then, at all kinds of diſtance of the Earth from the Sun, it is eaſy to calculate how much the duration of the tranſit would be ſhortened by the motion of an obſerver on the Earth's ſurface, on the ſide of the Earth next to Venus, and who is then moving in a contrary direction to the motion of Venus in her orbit, than the duration of the tranſit would be to an obſerver at the Earth's center, or even on its ſurface if the Earth had no motion on its axis; in which caſe, the obſerver on the ſurface would be at reſt. But as that obſerver is really in motion with the Earth, when the duration of the tranſit is obſerved by him, and, conſequently, known how much ſhorter it appeared to him, than it would have done if he had been at reſt; the diſtance of the Earth from the Sun may thereby be found: which, as I told you already, is thereupon computed to be 95,173,000 Engliſh miles.

*E.* The diſtance of the Earth from the Sun, in miles, being known; I ſhould be glad to know how you find the diſtances of all the other planets from the Sun. For we cannot ſend people from the Earth to thoſe planets, to obſerve tranſits.

*N.* I told you already, in our ſecond dialogue, that the relative or comparative diſtances of all the planets from the Sun are known long ago, both by the ſtated laws of nature, and by obſervation; and that they are as follows.

If we ſuppoſe the Earth's diſtance from the Sun to be divided into 100,000 equal parts, (let theſe parts contain how many miles they will) Mercury's diſtance from the Sun muſt be equal to 38,710 of theſe parts; Venus's diſtance, 72,333; Mars's diſtance, 152,369; Jupiter's, 520,096; and Saturn's diſtance, 954,006. Now, as the Number of miles is in proportion to the number of parts, and the 100,000 parts, by which the Earth is diſtant from the Sun, contain 95,173,000 miles; we ſay, by the rule of three, as 100,000 parts are to 95,173,000 miles; ſo are 38,710, Mercury's diſtance from the Sun in parts, to 36,841,468, his diſtance from the Sun in miles. So are 72,333, Venus's diſtance from the Sun in parts, to 68,891,486, her diſtance from the Sun in miles. So likewiſe are 152,369, Mars's diſtance from the Sun in parts, to 145,014,148, his diſtance from the Sun in miles. And ſo are 520,096, Jupiter's diſtance from the Sun in parts, to 494,990,976, his diſtance from the Sun in miles. And laſtly, (carrying on the proportions) ſo are 954,006, Saturn's diſtance from the Sun in parts, to 907,956,130, his diſtance from the Sun in miles.

*E.* I thank you, brother, for having explained the whole of this matter ſo much to my ſatisfaction. But I have heard that the late tranſit was obſerved by people at very different parts of the Earth ——Pray did you find, that all the obſervations (as you got accounts of them) agreed ſo well, as to give all the ſame concluſion.

*N.* I cannot ſay they did, ſo nearly as we could wiſh; which might have been owing to two cauſes. Firſt, that the differences of longitude (as it is called) between many places where thoſe obſervations were made, are not yet well aſcertained : and ſecondly, that all the obſervers did not uſe teleſcopes of an equal magnifying power, which they ſhould have agreed to do beforehand. And undoubtedly, they who uſed the higheſt magnifying teleſcopes, could more accurately determine the inſtants of Venus's two internal contacts with the Sun, than thoſe could who uſed ſmaller magnifying teleſcopes. But 'tis to be hoped, that all proper care will be taken, in obſerving the tranſit on the third of June, 1769. And aſtronomers will do well to make the moſt and beſt of it they can ; as there will not be another tranſit in leſs than 105 years afterward.

*E.* How can *that* be ?—For as the Earth goes round the Sun in a year, and Venus in 225 days ; I ſhould think, that Venus would paſs between the Earth and the Sun once every two years at moſt.

*N.* So ſhe would, once in every 584 days, if her orbit lay in the ſame plane with the Earth's orbit, like one circle made within another on a flat paper. But one half of Venus's orbit lies on the North-ſide of the plane of the Earth's orbit ; and the other half on the South-ſide of it : ſo that her orbit only croſſes the Earth's orbit in two oppoſite points. And therefore, Venus can only paſs directly between the Earth and the Sun, when, at the times of her conjunctions with the Sun, ſhe is either in or near one or other of thoſe points. At all other times, ſhe either paſſes above or below the Sun, and is then inviſible, on account of her dark ſide being toward the Earth. But its being ſo alſo, at the time of her late tranſit, made her very conſpicuous on the Sun, like a black patch on a circular piece of white paper. At her laſt tranſit, ſhe paſſed below the Sun's center, about a third part of the Sun's breadth ; and at her next, ſhe will paſs as far above it.

*E*. I underſtand this thoroughly.——But, I think there are ſome lines in the figure (PLATE III. *Fig.* 1.) which you have not yet explained.

*N*. Then, ſhew me them, and I will.

*E*. They are the lines *N E K* and *n e L*.

*N*. True: I had almoſt forgot them. Suppoſe an obſerver at *N*, on the ſide of the Earth fartheſt from Venus, to be carried from *N* to *n*, in the ſame direction with Venus's motion in her orbit from *E* to *e*, in the ſame time that an obſerver at *a* is carried from *a* to *b*, in a contrary direction to the motion of Venus in her orbit: the duration of the tranſit will be longer, as ſeen by the obſerver who is carried from *N* to *n*, than it would be to an obſerver at reſt at the Earth's center *C*. For, when Venus is in her orbit at *E*, ſhe will appear upon the Sun at *K*, as ſeen from *N* in the right line *N E K*; but ſhe muſt go on from *E* to *F* before ſhe can be ſeen from *C*, upon the Sun, in the right line *C F K*: and, as ſeen from *C*, in the right line *C f L*, ſhe will appear as juſt beginning to leave the Sun, at *L*, when ſhe is at *f* in her orbit. But ſhe muſt move on, from *f* to *e*, before ſhe can appear as beginning to leave the Sun when ſeen by the obſerver at *n*, who is carried from *N* to *n* by the Earth's motion on its axis, in the time of Venus's moving from *E* to *e* in her orbit. So that the viſible duration of the tranſit will be longer as ſeen by an obſerver who is carried from *N* to *n*, then it would be to an obſerver at reſt; and ſhorter, as ſeen by an obſerver who is carried from *a* to *b*. And the difference between theſe viſible durations will be of greater advantage towards finding the Earth's diſtance from the Sun, than what could be gained only from obſervations made on the ſide of the Earth which is neareſt to Venus, during the time of her tranſit.

*E*. Pray, who was it that firſt thought of this method of finding the diſtances of the planets from the Sun? I imagine he muſt have been a very great aſtronomer.

*N.* He was ſo indeed; the man who firſt propoſed this method was the great Doctor HALLEY. And as he was morally certain, that, according to the common courſe of nature, he could not live to ſee that tranſit; he moſt earneſtly recommended it to future aſtronomers, that they might obſerve it when he was dead. And, in order to furniſh them with all proper information, he gave in a paper on the ſubject to the Royal Society; which paper was, ſoon after, publiſhed in the Philoſophical Tranſactions.

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# DIALOGUE V.

## *On the method of finding* LATITUDES *and* LONGITUDES *of* PLACES.

*Neander.*

GOOD-morrow, ſiſter:—you have been later than uſual of coming this morning.—What's the matter? You look pale.

*Eudoſia.* I was taken ill, laſt night about twelve, of an aſthma, which frightened me, as I never was ſo before; and kept me awake till five o'clock this morning. Then it left me, and I fell aſleep, and have quite over-ſleeped my time; for now it is eight o'clock.

*N.* Why did you not ring your bell, in order that ſomething might have been brought to relieve you? eſpecially as you know that our mother (among many other good medicines) always keeps an electuary of honey,

ney, powder of liquorice, of elecampane, ſeeds of aniſe, and flower of ſulphur; which is exceeding good for that diſorder, and has cured many of it.

*E.* I was loath to ſurprize any body in the night, eſpecially as the aſthma did not continue long violent.—I raiſed my head a good deal; ſo it left me gradually; and now I feel nothing of it.

*N.* I am very glad of *that.*—But I think it would be quite wrong to enter upon any ſuch ſubject this morning, as we have already been about. And therefore, I hope you do not come now with any ſuch intention.

*E.* Indeed I do, if it were but to take off my drowſineſs: and I feel no other ailment at preſent.

*N.* Well then;—with what ſubject ſhall I entertain you this morning?

*E.* I heard you yeſterday, for the firſt time, mention the *Longitudes of places.* But as I ſcarce know what either *Longitude* or *Latitude* means, I ſhould be glad to know: eſpecially as we have heard ſo much lately about finding the Longitude. And as I never heard of any difficulty about finding the Latitude, I imagine, the latter is much more eaſily found than the former.

*N.* It is ſo indeed, ſiſter.

*E.* What is the reaſon of that?—But I believe my queſtion is premature: for I ſhould have aſked firſt, what thoſe terms mean?

*N.* Right, *Eudoſia*; and now I will inform you.——*Every circle*, be it great or ſmall, is divided (or ſuppoſed to be divided) into 360 equal parts, called *Degrees.* Now, if we take a great circle round the Earth, which divides the Earth into two equal parts, every degree of that circle contains 69$^{1}$ Engliſh miles: as is the caſe with the degrees of the equator, and nearly ſo with thoſe of a great circle taken round the Earth, through the North and South poles.

The *Latitude* of a place is the number of degrees that the place is from the Equator, towards the North or South pole: and is denominated *North* or *South*, as the given place is on the North or South ſide of the Equator.—Thus in the little globe, (*Fig.* 1. of PLATE I.) all the places in the northern hemiſphire, from every point of the Equator to the North pole, have North Latitude: and all the places from every point of the Equator to the South pole, have South Latitude. As the poles are the fartheſt points of the Earth from the equator, they have the greateſt Latitude; which is 90 degrees, or a fourth part of 360, the whole circumference of the globe.

The North and South points, or poles of the Heaven, are directly over the North and South poles of the Earth. And therefore, as the Earth turns round its axis, which terminates in its North and South poles, every point of its ſurface is carried round in 24 hours, except its poles, which are at reſt. This motion of the Earth will cauſe an apparent motion of every point of the heaven, in a direction contrary to the Earth's motion, excepting its poles, which appear always at reſt; becauſe they are directly over the poles of the Earth, which are at reſt.

*E.* May I put in a word juſt now, before you proceed farther?

*N.* Why not.

*E.* I ſhould think, that the poles of the Heaven would change among the ſtars, on account of the Earth's motion round the Sun in a year. For, undoubtedly, if the Earth's axis (or line on which it turns round every 24 hours) were produced to the Heaven, it would deſcribe a circle therein, equal in diameter to that of its whole orbit; which you have already told me, is 190 millions of miles.

*N.* And ſo it does.—But if it ſhould, by its track, make as dark a circle in the Heaven, as can be made with ink by a pair of compaſſes on paper; the diſtance of the ſtarry Heaven is ſo great from us, that a circle therein of 190 millions of miles in diameter, would not appear ſo big to us as the ſmalleſt dott you can poſſibly make with a fine pen upon paper. Which ſhews, that if the Earth were as big as would fill its whole orbit, it would appear no bigger than a dimenſionleſs point, if ſeen from the ſtars. For, notwithſtanding the Earth's conſtantly changing its place in its orbit, the poles of the Heaven could never be perceived to change their places, a ſingle viſible point, even when obſerved with the niceſt inſtruments. And therefore, we always conſider the poles of the Heaven to be fixed points; and to keep conſtantly juſt over the poles of the Earth.

*E.* You have fatisfied me entirely on this head; and at the ſame time, convinced me, that the diſtance of the ſtars muſt be inconceivably great. Now, pleaſe to proceed.

*N.* Now, let us ſuppoſe a great circle to be drawn round the Heaven, through its North and South poles, and to be divided into 360 degrees, like a circle drawn round the Earth through *its* North and South poles.

As the Earth is but a point in compariſon to the diſtance of the ſtarry Heaven; let us be on what part of the Earth we will, we ſee juſt one half of the Heaven, if the horizon, or limit of our view all around, be not intercepted by hills. And as the poles of the Heaven are directly over the poles of the Earth; ſo the equinoctial in the Heaven is directly over the Earth's equator, all around.

Now, as the Earth is round, and the Heaven appears to us to be round like the concave ſurface of a great ſphere or hollow globe; 'tis plain, that if we were at the Earth's equator, the equinoctial in the Heaven would be over our heads; and the North and South points, or poles of the Heaven, would appear to be in the North and South points of our horizon, or limit of view. But if we go one degree from the equator, towards either the North or South pole of the Earth, the like pole of the Heaven would appear to be one degree elevated above our horizon, becauſe we would ſee a degree of the Heaven below it; and the contrary pole of the Heaven would be one degree hid below the limit of our view.—If we go two degrees from the equator, the pole will appear to be two degrees elevated above our horizon; and ſo on, till we go to either of the Earth's poles, 90 degrees from the equator; and then, the like pole of the Heaven would be juſt over our head, or 90 degrees above our horizon; which is the greateſt elevation it can have, as ſeen from any part of the Earth. And as the number of degrees we are from the Earth's equator is called our Latitude, ſo the number of degrees of the elevation of the celeſtial pole is equal thereto. At London the North pole of the Heaven is elevated 51½ degrees above the horizon; which ſhews, that London has 51½ degrees of North Latitude from the equator.

And as Latitude begins at the equator, the places thereon have no Latitude at all.

*E.* But how can you tell by what number of degrees the pole is elevated? for there is no viſible circle in the Heaven divided into degrees, to reckon by.

*N.* But we have an inſtrument called a Quadrant, which is a quarter of a circle, drawn on a plate of metal, and divided into 90 degrees; and it has a plumb line with a weight hanging from its center, which line always hangs towards the Earth's center, when allowed to hang freely. And if we look at the pole along one of the ſtraight edges of the quadrant, the other edge will be as many degrees from the plumb line, as are equal to the number of degrees of the pole's elevation above the horizon of our place.—And, by that means, the elevation of the pole, and conſequently the Latitude of the place is known.

*E.* Is there a ſtar fixed exactly in the North pole, by which means you can know by ſight where *that* pole is?

*N.* No: but there is a ſtar of the ſecond magnitude, about two degrees from the North pole, and it is called *the pole ſtar.* And as the Earth's motion on its axis cauſeth an apparent motion of all the ſtars round the poles of the Heaven; the pole ſtar appears to us to deſcribe a circle, of four degrees diameter, round the pole it ſelf, every 24 hours. And therefore, if we ſubtract two degrees from the greateſt obſerved height of the pole ſtar, or add two degrees to the leaſt obſerved height thereof; the reſult gives the elevation of the pole at the place of obſervation.

As the North pole is elevated 51½ degrees above the horizon of London; all thoſe ſtars which are within 51½ of that pole never ſet below the horizon of London. And therefore, if the greateſt and leaſt altitudes of any of theſe ſtars be taken with a quadrant, half the difference of theſe altitudes being added to the leaſt, or ſubtracted from the greateſt, gives the elevation of the pole above the horizon.

And thus, we can very eaſily and accurately find the Latitude of any place, by means of any ſtar which never ſets below the horizon of that place.

The Latitude of any place may alſo be found by the Sun's altitude at noon, on any day of the year, quite independent of the ſtars. — I will firſt endeavour to ſhew you the reaſon of this, and then ſhew you the method.

The Equinoctial in the Heaven is directly over the Equator on the Earth. And juſt as many degrees as the Latitude of any given place is from the Equator, ſo many degrees is the point of the heaven, which is over the place, from the equinoctial. Conſequently, if we can find how many degrees the point of the Heaven, which is directly over our place, is from the Equinoctial, we thereby find how many degrees our place is from the Equator; or our Latitude.

The Sun is in the Equinoctial twice every year; namely, on the 20th of March, and 23d of September; and then he is directly over the Earth's Equator. From the 20th of March to the 23d of September, the Sun is on the North-ſide of the Equinoctial, and from the 23d of September to the 20th of March, he is on the South-ſide of it. The number of degrees that the ſun is from the Equinoctial, on any day of the year, is called *the Sun's Declination* for that day; and is denominated *North* or *South*, as the ſun is on the North or South ſide of the Equinoctial.——So that, *Declination* in the Heaven, is the ſame as *Latitude* on the Earth.

There are tables, ready calculated, which ſhew what the Sun's declination is, at the noon of every day of the year; as it is North or South on that day.——And the point of the heaven which is directly over any place, is 90 degrees above the horizon of that place.

Now, to find the Latitude of the place, as ſuppoſe London, which is on the North ſide of the Equator; obſerve the Sun's altitude at noon, by means of a quadrant, on any day of the year: and then, if, by the tables, you find the Sun's declination to be North on that day, ſubſtract the declination from the Sun's meridian altitude, (that is from his height at mid-day, as found by the quadrant) and the remainder will be the height of the equinoctial; which height being ſubſtraced from 90 degrees, will give the Latitude of the place.

Thus, on the 21ſt of June, the tables ſhew us, that the Sun's declination is 23 ½ degrees north; and if the Sun's altitude be obſerved with a quadrant on the noon of that day, the altitude will be found to be juſt 62 degrees.——Now, ſubſtract 23 ½ degrees from 62, and the remainder will be 38 ½ degrees for the height or elevation of the higheſt point of the Equinoctial above the horizon of London; which height being ſubſtracted from 90 degrees, leaves remaining 51 ½ degrees for the Latitude of London.

If the Sun's declination be South, add its quantity to the Sun's obſerved altitude at noon, and the ſum will be the elevation of the higheſt point of the equinoctial above the horizon of the place; which elevation being ſubſtracted from 90 degrees, will leave a remainder equal to the Latitude of the place.

Thus, on the 21ſt of December, the table ſhews us, that the Sun's declination is 23 ½ degrees South: and if his altitude at noon be taken at London on that day by a quadrant, it will be found to be juſt 15 degrees; which being added to 23 ½ degrees South declination, gives 38 ½ degrees for the height of the equinoctial, which height being ſubſtracted from 90 degrees, leaves 51 ½ remaining, for the Latitude of London, as before. ——— Do you underſtand all this *Eudoſia*?

*E.* I think I do, on account of the reaſons you have given for the proceſs.——But I will conſider it by and by; and then tell you if I find any difficulty.

*N.* Do ſo: and now we will talk about the Longitude. The curve lines which you ſee drawn on the globe, from pole to pole (PLATE I. *Fig.* 1.) are called *Meridians*; and each of them is a meridian to every place through which it paſſes; becauſe when it comes even with the Sun, by the turning of the globe on its axis, the Sun is then at the greateſt height, as ſeen from all places on that meridian; and conſequently, it is then mid-day or noon to each of them.——There are only 24 meridian ſemicircles on the globe, at equal diſtances from each other; but we may ſuppoſe the whole ſpaces between them to be filled up with other ſuch meridians, becauſe every place, which is ever ſo little to the Eaſt or Weſt from the meridian of any given place, has a different meridian from *that* of the given place.

The whole circumference of the Equator is divided into 360 equal parts or degrees: and the Engliſh aſtronomers and geographers begin (what they call) the Longitude, at the meridian of London, and thence reckon the Longitudes of other places to the Eaſt or Weſt, as the meridians of thoſe places lie Eaſt or Weſt from the meridian of London. So that, the Longitude of any place, Eaſt or Weſt of the meridian of London, is equal to the number of degrees intercepted between the meridian of that place and the meridian of London; according to the Engliſh way of reckoning. Thus, a meridian drawn through *Copenhagen*, in *Denmark*, would cut the Equator 13 degrees eaſtward of that point where the meridian of London cuts it; and a meridian drawn through *Philadelphia*, in North America, would cut the Equator 74 degrees weſtward of the point where the meridian of London cuts it: and therefore, we ſay, the Longitude of *Copenhagen* is 13 degrees Eaſt from the meridian of London (which is termed *the firſt meridian* by the Engliſh) and the Longitude of *Philadelphia* is 74 degrees Weſt.

All people, who know what *Latitude* and *Longitude* mean, reckon Latitude to begin at the Equator, that they may find the Latitude by the elevation of the pole above the horizon.——But, as they may begin the Longitude at the meridian of any place; I ſuppoſe moſt nations reckon the Longitude of all other places from the meridian of the principal city of their own kingdom or nation.

*E.* Why is it ſo difficult a matter to find the Longitude of any place, from the meridian of any other place, in compariſon of finding the Latitude ?

*N.* Becauſe we have a fixt point, or pole, in the heaven, which ſhews us our Latitude by its elevation above the horizon of our place : but there is no viſible meridian in the Heaven, to keep directly over the meridian of any place on the Earth.——If there were ſuch a meridian, the Longitudes of all other places from it might be as eaſily found, by its elevation above their horizons, as their Latitudes are found by the elevation of the pole, or by the declination of the Sun from the Equator.

*E.* I underſtand you perfectly well.——But, pray, what are the beſt methods that have been yet propoſed for finding the Longitude ?

*N.* The beſt method, in theory, is by a machine that will meaſure time exactly, ſo as to go as true at ſea, as a good clock does on land.

*E.* Pleaſe to explain this.

*N.* The Earth's circumference is 360 degrees ; and as it turns round its axis eaſtward every 24 hours, it turns 15 degrees every hour : for, 24 times 15 is 360. Therefore, every place whoſe meridian is 15 degrees Eaſt of the meridian of London, will have noon, and every other hour, one hour ſooner than it is ſo at the meridian of London. Every place whoſe meridian is 30 degrees eaſtward of the meridian of London, will have noon, and every other hour, two hours ſooner than it is ſo at the meridian of London ; and ſo on : the time always differing one hour for every 15 degrees of Longitude. On the contrary, every place whoſe meridian is 15 degrees Weſt from the meridian of London, will have noon, and every other hour, one hour later than it is ſo at the meridian of London; and every place whoſe meridian is 30 degrees Weſt from the meridian of London, will have noon, and every other hour, two hours later than it is ſo at the meridian of London; and ſo on.

*E* Although this ſeems plain, I ſhould be glad to have it illuſtrated by a figure.

*N.* And here is one (*Fig.* 2. of PLATE III.) ready for you; in which, let *S* be the Sun *a b c d e f*, &c. the Earth, turning eaſtward round its axis, in 24 hours, according to the order of the letters. Let *P* be the North pole of the Earth, and *a P*, *b P*, *c P*, *d P*, &c. be as much of 24 meridian ſemicircles as can be ſhewn in the figure, at 15 degrees diſtance from each other; and ſuppoſe *a P* to be the meridian of London.

Then, whichever ſide of the Earth is at any time turned toward the ſun, it will be *day* on that ſide, and *night* on the other; as expreſſed by the *light* and ſhaded parts of the Earth in the figure. And, as it muſt be XII o'clock at noon on any meridian which is turned toward the ſun, at any moment of abſolute time, becauſe *that* meridian will then be in the middle of the enlightened half of the Earth, as on the meridian *P a*; it is plain that it will be twelve o'clock at night, at the ſame inſtant, on the oppoſite meridian *n P*, becauſe it is then in the middle of the dark. VI o'clock in the morning on the meridian *t P*, and VI in the evening on the meridian *g P*; and ſo, all the intermediate hours, on the intermediate meridians, at the very inſtant when it is noon on the meridian *P a*. So that, ſuppoſing *P a* to be the meridian of London, it is plain, that when it is XII o'clock *there*, it will be 1 o'clock in the afternoon on the meridian *P b*, becauſe *that* meridian is paſt by the ſun 15 degrees, or one hour, to the eaſtward; II o'clock in the afternoon on the meridian *P c*: III o'clock on the meridian *P d*; and ſo on. But, it can only be XI in the forenoon, on the meridian *P z*, when it is noon on the meridian *P a*; becauſe *P z* is then an hour ſhort of being even with the ſun: X o'clock in the forenoon on the meridian *P y*, becauſe that meridian wants two hours of being even with the ſun; and ſo on.

Now, as every maſter of a ſhip knows how to find the time of the day at the place of his ſhip, by the height of the ſun; or the time of the night by the height of any given ſtar that revolves at a good diſtance from either of the celeſtial poles; if he firſt finds the Latitude of the place of his ſhip: he may find the Longitude of that place in the following manner, if he can depend upon the true going of his watch.

Before he ſets out from any port, as ſuppoſe from London, let him ſet his watch to the exact time at *that* port: and then, let him ſail where he will, his watch will always ſhew him what the time is at that port from which he ſet out.

Now, ſuppoſe him to be at ſea, on his way to the Weſt Indies; and that he has ſailed from London at *a* as far weſtward as *x*, and then wants to find the Longitude of the place of his ſhip at *x*. He firſt finds the Latitude of the place *x*, and then, by the altitude of the ſun, finds the time at that place; which we ſhall ſuppoſe to be IX o'clock in the morning: he then looks at his watch, which ſhews the time at London, on the meridian *P a*; and finds that it is XII o'clock at noon on the meridian of London. By this he knows, that he is three hours to the Weſt of London; and as every hour of time anſwers to 15 degrees of Longitude, he finds that the meridian of the place of his ſhip is 3 times 15, or 45 degrees Weſt from the meridian of London. And, as every hour anſwers to 15 degrees of Longitude, ſo every four minutes anſwers to one degree. If he had been as far eaſtward (as at *d*) from the meridian of London, he would have found it to be III o'clock in the afternoon at the place of his ſhip, when his watch would have ſhewn him that it was then only mid-day at London: and ſo, in *that* caſe, he would have known that the Longitude of his ſhip was 45 degrees Eaſt from the meridian of London.

*E.* This appears to me to be a very rational and eaſy method of finding the Longitude, if a watch can be made that will keep exact time at ſea.—Pray has there ever been ſuch a watch made, ſo as that it can be depended upon? for otherwiſe I ſhould think it very dangerous; becauſe, for every four minutes that it would either gain or loſe, it would cauſe an error of a whole degree in reckoning the Longitude.

*N.* Mr. *Harriſon* has ſucceeded the beſt of any who ever yet attempted to make ſuch a watch. But *that* watch has been found not to keep time quite ſo exactly as was expected, after ſome months trial at the Royal Obſervatory at Greenwich. Yet it muſt be acknowledged that Mr. *Harriſon* has very great merit, and deſerves the reward he has got for his ingenuity: and many are of opinion, that he can ſtill make a watch that will meaſure time more exactly than the one which has been already tried (and for which he has got the reward), as it is the only one he ever made.

Another method (and which is a very ſure one) for finding the Longitude, has been practiſed for many years: and *that* is, by the eclipſes of Jupiter's ſatellites; but it is attended with two inconveniencies: firſt, as it requires the teleſcope to be quite ſteady, by which thoſe eclipſes are obſerved; it cannot be put in practice at ſea, on account of the unſteadineſs of the ſhip: and ſecondly, no obſervations of theſe eclipſes can be made in the day-time, becauſe Jupiter is not then viſible.

*E.* But I ſhould think it muſt ſtill be very uſeful in finding the Longitudes of places on the land, where the teleſcope may be kept quite ſteady.—Pray, explain the method by which the Longitude has been thus found.

*N.* The Engliſh aſtronomers have calculated tables which ſhew the times of thoſe eclipſes, all the year round, on the meridian of London; and the French have done the like for the meridian of Paris.—Now, ſuppoſe an Engliſhman to be at *Kingſton* in *Jamaica*, and that he obſerves either of Jupiter's moons to be eclipſed juſt at One o'clock in the morning: he looks at the tables, to ſee at what time the ſame eclipſe is on the meridian of London; and finds the time *there* to be at 8 minutes after VI in the morning. The difference of the times, as reckoned at *London* and at *Kingſton* in Jamaica, is thus found to be 5 hours 8 minutes, or 308 minutes; which being divided by 4, (becauſe 4 minutes of time anſwer to one degree of Longitude) quotes 77 for the number of degrees by which the meridian of Kingſton is Weſt from the meridian of London: and thus he finds, that Kingſton is in 77 degrees of Weſt Longitude from London.

*E.* You have explained theſe matters very fully; and I thank you for it.

*N.* I thought to have done it in much fewer words; and am afraid I have tired you this morning, as you cannot be very well after having ſuch a bad night.

*E.* But I am quite well now brother; and you have finiſhed in very good time, as the bell juſt rings for breakfaſt.

# DIALOGUE VI.

## *On the* CAUSES *of the different lengths of* DAYS *and* NIGHTS, *the viciſſitudes of* SEASONS, *and the various phaſes of the* MOON.

*Neander.*

I AM very glad to ſee you ſo early this morning, *Eudoſia.*—I hope you reſted well laſt night, and had no return of your late complaint.

*Eudoſia.* I ſlept very well from ten o'clock till five; and am quite well,

*N.* I am very glad to hear it.—What ſubject do you propoſe for us to enter upon, this morning?

*E.* I ſhould be glad to know the reaſon why the days and nights are of different lengths at different times of the year. For, although 'tis plain, that the turning of the Earth round its axis once every 24 hours, muſt cauſe a continual ſucceſſion of day and night in that time; the ſame as if the Earth were at reſt, and the Sun moved round it in 24 hours; I do not underſtand the reaſon why the days and nights are continually varying in their lengths, unleſs it were by a particular motion of the Sun northward and ſouthward, acroſs the Equator in a year.—But, from what you have already told me, it appears plain, by the ſtated laws of nature, that the Sun cannot have any ſuch motion

*N.* Indeed he cannot.—And you ſhall ſoon ſee the reaſon of the different lengths of days and night, and of all the four ſeaſons of the year, without any motion of the Sun northward and ſouthward acroſs the Equator.—Pleaſe to light *that* candle, by way of a Sun, and ſet it upon the table, whilſt I ſhut the windows; ſo that we may have no light in the room but from the candle.

*E.* There it is, brother.

*N.* Now, I put a wire axis through our ſmall three inch globe, ſo as to reach a little way out from its ſurface in the North and South poles.——I move the globe round the flame of the candle, keeping it always at the ſame height from the table, and its axis perpendicular to the table: and you ſee that the candle is always even with the Equator of the globe, and enlightens it juſt from pole to pole.

*E.* Exactly ſo.

*N.* And that one half of the globe is enlightened by the candle, whilſt the other half is not: and conſequently, that it appears as if it were *day* on the ſide of the globe next the candle, and *night* on the oppoſite ſide.

*E.* Very plain.

*N.* I now turn the globe round its axis many times during the time I move it round the candle as before; and you ſee that every part of its ſurface, from the North pole to the South, goes equally through the light and ſhade. So that, if the globe was turned round its axis once every 24 hours, and carried round about the candle once in a year, every point of its ſurface from pole to pole, would be twelve hours in the light, and twelve hours in the dark.

Pl. IV.

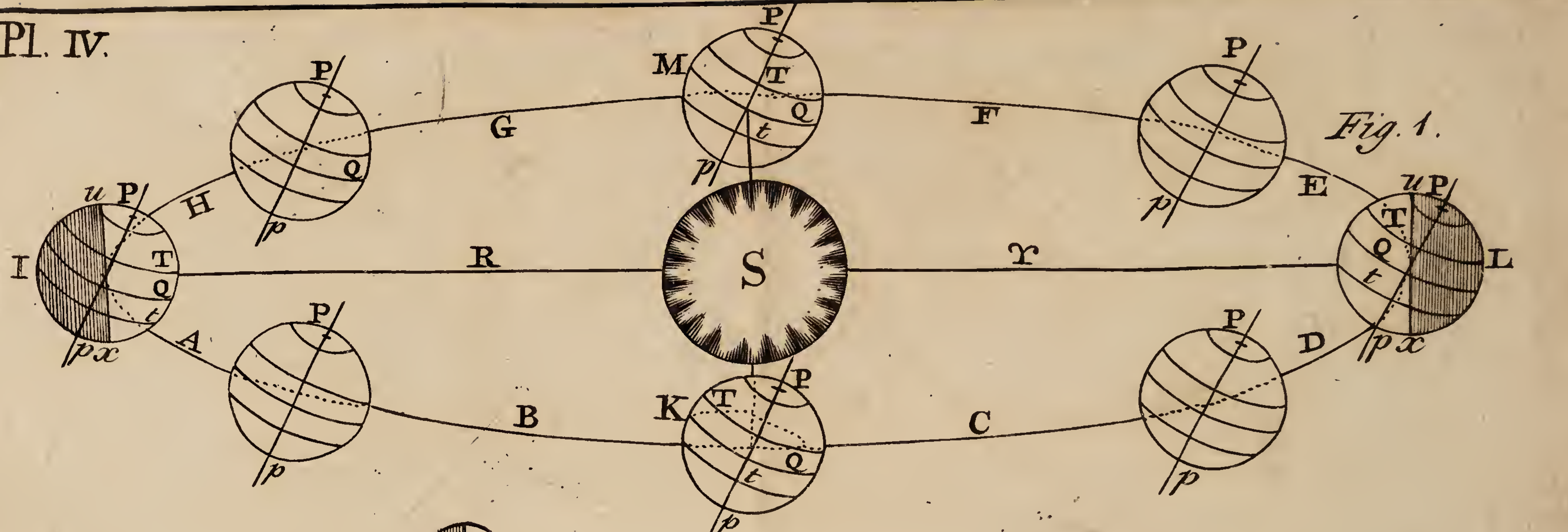

*Fig. 1.*

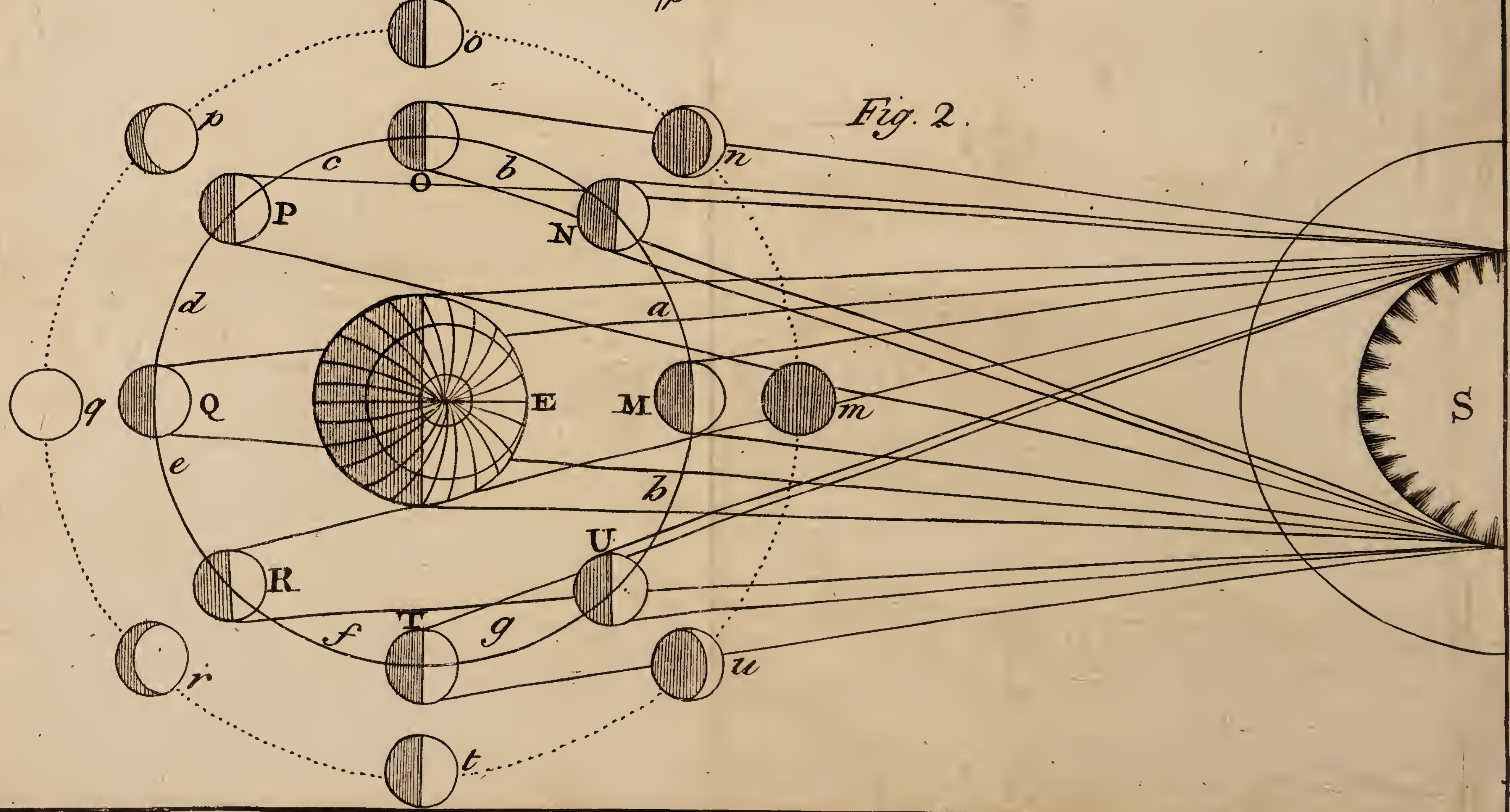

*Fig. 2.*

*E.* Undoubtedly it would.

*N.* Then, you ſee, that ſuppoſing the candle to have no motion from one ſide of the Equator to the other, and the axis of the globe to keep perpendicular to its orbit, in its whole courſe round the candle; the days and nights could never vary in their length.

*E.* Self-evident.

*N.* I now incline the North pole of the axis a little toward the candle, and turn the globe round its axis.—You now ſee that the candle ſhines as far over the North pole as the axis of the globe is inclined toward the candle; and that all thoſe places of the northern hemiſphere which go through the dark, go through leſs of it than they do of the light; ſo that their days are longer than their nights: and the candle, being on the North-ſide of the Equator, ſhines as far ſhort of the South pole, as it ſhines over the North pole: and conſequently, all the places on the ſouthern hemiſphere of the globe, which go through the light, go through a leſs portion of it than they do of the dark; and ſo have their days ſhorter than their nights.

But, make the North pole of the axis decline from the candle, and turn the globe round its axis; the candle will not enlighten the globe to the North pole, but it will ſhine round the South pole. And now, all the northern places of the globe which go through the light, go through leſs of it than they do of the dark; ſo that the days are ſhorter than the nights on the North-ſide of the Equator, and the contrary on the South-ſide of it. ——You now ſee, that turning the poles of the Earth alternately, more or leſs, toward and from the Sun, will have the ſame effect, as if the Sun really moved northward and ſouthward, to different ſides of the Equator.

*E.* It will, indeed. ——But do the poles of the Earth incline towards the Sun, and from him in that manner, at different times of the year?

*N.* They do: and here is a figure, (PLATE IV. *Fig.* 1.) by which the whole of that matter may be very eaſily explained.

Let *A B C D E F G H A* repreſent the Earth's orbit (ſeen obliquely, which cauſeth it to appear of an elliptical ſhape.) And let *I* be the Earth, going round the Sun *S*, according to the order of the letters *A*, *B*, *C*, *D*, &c. once every year.

Now, ſuppoſe a great circle *P u I p x*, to be drawn round the Earth, through its North pole *P* and its South pole *p*; and let *Q* be the Equator.

Divide the great circle *P u I p x* into 360 equal parts or degrees; and ſet off 23½ of theſe degrees from *P* to *u*. Then, at the diſtance *P u* from the North pole, draw a circle all around it; which call *the North polar circle:* and ſuppoſe juſt ſuch another circle to be drawn around the South pole.

Make the Earth's axis *P p* incline 23½ degrees toward the right hand ſide of the plate; and let the Earth *I* be carried round the Sun *S*, in the orbit *A*, *B*, *C*, *D*, &c. in the time of its turning 365¼ times round its axis: and, in its whole courſe, let its axis *P p* ſtill incline 23½ degrees toward the right-hand ſide of the plate.

Then 'tis plain, that when the Earth is at *I*, the whole North polar circle falls within the enlightned part of the Earth; and all the northern places between the Equator *Q* and the North polar circle *u* are more in the light than in the dark: and therefore, as the Earth turns round its axis, theſe places will have longer days than they have nights: and the Sun will point as far North of the Equator *Q*, as ſhewn by the ſtrait line *R*, as he ſhines round the North pole *P*; for the diſtance *Q T*, northward from the Equator, is equal to the diſtance *P u* from the North pole; which is 23½ degrees.——This is the Earth's poſition on the

21ſt of June, when our days are at the longeſt, and nights at the ſhorteſt.

At the diſtance *Q T* (23½ degrees northward from the Equator) deſcribe the circle *T*, round the globe, parallel to the Equator: and as the Sun is directly over the circle *T*, in the right line *R*, and can never be farther North of the Equator; but begins then to recede, as it were, ſouthward from the circle, *T*, that circle is called *the Northern Tropic*, or limit of the Sun's greateſt North declination from the Equator *Q*.

As the Earth moves on in its orbit, from *I to K*, its axis *P p* inclines more and more ſidewiſe to the Sun *S*; as it ſtill keeps parallel to the poſition it had when the Earth was at *I*: for which reaſon, the northern places are gradually turned away from the Sun; and their days grow ſhorter, and their nights longer.

When the Earth is at *K*, its axis *P p* inclines neither toward the Sun nor from him, but is ſidewiſe to him: ſo that the Sun is then directly over the Equator, and enlightens the Earth juſt from pole to pole. And, as the Earth's rotation on its axis then carries all the parts of its ſurface between the poles equally through the light and the dark, the days and nights are equally long at all places of the Earth. This is the Earth's poſition on the 23d of September.

As the Earth advances from *K* to *L*, through the part *C D* of its orbit, the North pole *P* and all the northern places of the Earth are gradually more and more turned away from the ſun *S*: and thoſe places of the northern hemiſphere which go through the light and the dark, go through more of the dark than of the light; ſo that their days become gradually ſhorter, and their nights longer.

When the Earth comes to *L* in its orbit, its North pole *P* is as much turned away from the Sun *S*, as it was turned toward him when the Earth was at *I*: and therefore,

fore, when the Earth is at *L*, the whole North polar circle *u* is in the dark; and the Sun points 23½ degrees (as ſhewn by the right line *r*) to the South of the Equator *Q*; and is then over the circle *t*, which is parallel to the Equator, and is called *the ſouthern tropic*, becauſe it is the utmoſt limit of the Sun's South declination from the Equator. This is the Earth's poſition on the 21ſt of December, when all thoſe places in the northern hemiſphere, which go through the light and the dark, go through the leaſt portion of the light, and the greateſt of the dark, that they can do on any day of the year. And therefore, the days are then at the ſhorteſt, and nights at the longeſt, in the northern half of the Earth, all the way from the Equator *Q* to the North polar circle *u*; within which circle there is no day at all.

As the Earth advances from *L* to *M*, through the part *E F* of its orbit, its axis *P p* is gradually more and more turned ſidewiſe to the Sun; the northern places fall more and more into the light, and their days lengthen and nights ſhorten. And when the Earth comes to *M*, which is on the 20th of March, its axis neither inclines toward the Sun nor from him, but ſidewiſe to him. And then, the Sun is directly over the Equator *Q*, and enlightens the Earth from its North pole *P* to its South pole *p*: and as it turns round its axis, every place on its ſurface from pole to pole goes equally through the light and the dark; and has the day and night of an equal length, that is, twelve hours each.

Laſtly, as the Earth goes on from *M* to *I*, in the part *G H* of its orbit, its North pole *P*, and all its northern places from the Equator *Q* to that pole, advance gradually more and more into the light; and ſo, have their days longer and nights ſhorter, till the Earth comes to *I* on the 20th of June, when the days in thoſe places are at the longeſt, and nights at the ſhorteſt; becauſe they incline the moſt to the Sun that they can do on any day of the year; and conſequently, they then go through the greateſt portions of the light, and the leaſt of the dark, all the way from the Equator to the North polar circle *u*; within which circle there is then no darkneſs at all.

And thus, as the Earth's axis ſtill inclines toward one and the ſame ſide of the heavens, in its whole annual courſe round the Sun; as in the figure it does toward the right hand ſide of the plate; it is evident, that its axis muſt incline conſtantly, more or leſs, toward the Sun during our ſummer-half of the year; and more or leſs from him during our winter-half. That, when it is ſummer in the northern hemiſphere, it muſt be winter in the ſouthern, and the contrary: and that there can be no difference of ſeaſons at the Equator, becauſe it is in the middle between the poles, and always equally cut in halves by the boundary of light and darkneſs *u x*.

*E*. This very plainly ſhews the reaſon of the different lengths of days and nights, and alſo of all the variety of ſeaſons.——But, as I apprehend the matter, each pole, in its turn, muſt be continually in the light for half a year together; and in the dark for the other half: ſo that it appears there can be but one day and one night at each pole, in the whole year.

*N*. You are quite right, *Eudoſia*; and have told me the very thing that I was about to inform you of.

*E*. I came into your room yeſterday about one o'clock; but you happened then to be out: and ſeeing a book lying open on your table, I looked into it; and found mention made of the *ecliptic*, the *ſigns* thereof, and the *Sun's place*. Pray, what is the ecliptic, and what are its ſigns?

*N*. If the plane of the Earth's orbit were produced out to the ſtars, like a broad circular thin plate, its edge would form a great circle among the ſtars; which great circle (tho' only an imaginary one) we call *the Ecliptic*. And as the Earth moves in the plane of ſuch a circle, in its whole courſe round the Sun, it will be always ſeen from the Sun as moving in ſuch a circle among the ſtars: and, at any given time, in the *oppoſite* point of that circle to the point of it in which the Sun then appears as ſeen from the Earth. So that, as the Earth goes round the Sun once a year, the Sun will appear to us to deſcribe a great circle among the ſtars, in a year.

Aſtronomers divide this circle into twelve equal parts, called *Signs*, and each ſign into 30 equal parts called *Degrees*. And in *whatever* Sign and Degree the Earth would appear, as ſeen from the Sun, at any given time; the Sun muſt then appear in the *oppoſite* Sign and Degree as ſeen from the Earth: and the part of the Ecliptic in which the Sun's center appears to be, as ſeen from the Earth at any given inſtant of time, is called *the Sun's place in the Ecliptic*, at that time.

Theſe *Signs* are called *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpio*, *Sagittarius*, *Capricornus*, *Aquarius*, and *Piſces*. The month and days of the year, in which the Sun appears to enter theſe Signs, are as follows.

| | | | | | |
|---|---|---|---|---|---|
| *Aries*,<br>March<br>20 | *Taurus*,<br>April<br>20 | *Gemini*,<br>May<br>21 | *Cancer*,<br>June<br>21 | *Leo*,<br>July<br>23 | *Virgo*,<br>Auguſt<br>23 |
| *Libra*,<br>Sept.<br>23 | *Scorpio*,<br>Octob.<br>23 | *Sagittarius*,<br>Novemb.<br>22 | *Capricornus*,<br>Decemb.<br>21 | *Aquarius*,<br>Janu.<br>20 | *Piſces*,<br>Febr.<br>19 |

*E.* Then, let me ſee; I think I could tell, by this, what the Sun's place in the Ecliptic is, on any day of the year. Each Sign has 30 degrees; this is the 11th day of July, and the Sun does not enter *Leo* till the 23d; ſo that he muſt yet be in Cancer. Take 11 from 23, and there remains 12; ſo that the Sun is now 12 degrees ſhort of the laſt point of *Cancer* ; and conſequently, he is in the 18th degree thereof.

*N.* You are perfectly right, ſiſter ; and I think we have done with this part of our ſubject.

*E.* And will you allow me, this morning, to enter upon any other ?

*N.* Why not ; and continue it too till the bell calls us to breakfaſt.

*E.* Which, I hope, will not be in leſs than half an hour : and till then, I ſhould be glad to learn ſomething about the Moon.

*N.* Very well : it is your province to aſk queſtions, and mine to anſwer them.

*E.* What is the cauſe of the Moon's appearing of ſuch different ſhapes as ſhe does to us every month, always increaſing from change to full, and decreaſing from full to change ?

*N.* Be pleaſed to light the candle again, and ſet it on yonder table, at the farther end of the room, whilſt I cloſe the window-ſhutters. And then, do you ſtand at a good diſtance from the candle, and look toward it.

*E.* Very well, brother ;——Now,

*N.* Here is a ſmall ivory globe, with a wire through it, by way of an axis. I will now move *that* globe round your head ; and, as I carry it about, do you turn yourſelf round, and keep looking at it. Let the candle repreſent the Sun, your head the Earth, and the globe the Moon. As the candle can enlighten only that half of the globe which is turned toward it, ſo the Sun can only enlighten that half of the Moon which is at any time turned toward him. The other half is in the dark, and the Moon goes round the Earth in her orbit once a month.

As I carry the globe round your head, the dark ſide of it is toward you when it is between your head and the candle ;

candle; the light ſide when it is carried half round, or oppoſite to the candle with reſpect to your head; and, in the middle between theſe two poſitions, you have half the light and half the dark ſide toward you.

*E.* Very true.——And when the globe is between me and the candle, the whole of its enlightened ſide diſappears: when you move it a little way from that poſition, I ſee a little of its enlightened ſide, appearing horned, like the Moon when ſhe is a few days old. When you carry it a quarter round, I ſee half its enlightened ſide, which appears juſt like the Moon when ſhe is a quarter old. As you move it farther onward, I ſee more and more of its enlightened ſide; and it continues to increaſe like the Moon, till it is juſt oppoſite to the candle, when I ſee the whole of its enlightened ſide; and then it appears quite round, like the full Moon. After which, I ſee leſs and leſs of its enlightened ſide, which gradually decreaſes like the Moon, until you bring it again between me and the candle; and then, the whole of its enlightened ſide diſappears, as before.

*N.* And doth not this ſhew very plainly, why the Moon muſt appear to us to increaſe from the change to the full; and decreaſe from the full to the change?

*E.* Very plainly, indeed: and, I think, it alſo ſhews that the Moon does not ſhine by any light of her own; but only by reflecting the Sun's light that falls upon her. For, if ſhe ſhone by her own light, we ſhould always ſee her round, like the Sun.

*N.* *That* is a very good and juſt obſervation, ſiſter; and it is a remark that I might poſſibly have forgotten to make.

*E.* But, if you had not explained the different appearances of the Moon by means of a globe and a candle; how would you have done it by a figure?

*N.* Here is a figure for that purpoſe (PLATE IV. *Fig.* 2.) in which, let *S* repreſent the Sun, *E* the Earth, *M* the Moon; and *a b c d e f g h a* the Moon's orbit, in which ſhe goes round the Earth from change to change, according to the order of the letters; that is, eaſtward in the heavens; although the Earth's daily motion round its axis, the ſame way, being quicker than the Moon's progreſſive motion, makes her appear to go round weſtward. When the Moon is at *M*, between the Earth and the Sun, her dark ſide is then toward the Earth; and ſhe diſappears, becauſe *that* ſide reflects no light. When ſhe is at *N*, a little of her enlightened ſide will be ſeen from the Earth; and then ſhe will appear horned, as at *n*. When ſhe is at *O*, half her enlightened ſide will be toward the Earth, and ſhe will then appear as at *o*, or in her firſt quarter, being then got a quarter of her orbit out from between the Earth and the Sun. When ſhe is at *P*, more than half of her enlightened ſide is toward the Earth; and ſhe appears (what we call) Gibbous, as at *p*. When ſhe is oppoſite to the Sun, as at *Q*, the whole of her enlightened ſide is toward the Earth; and ſhe appears round and full, as at *q*.

*E.* Let me interrupt you a little here. Pray how can the Sun ſhine upon the Moon, when the Earth is directly between her and the Sun? For, I ſhould think, that the Earth would ſtop the Sun's light from going to the Moon.

*N.* It does ſometimes; and then the Moon is eclipſed: and ſometimes the Moon comes directly between the Earth and the Sun at the time of her change; and then we ſay, the Sun is eclipſed. But we ſhall talk of theſe matters afterward.

*E.* I am very glad of it: and now, Sir, pray proceed.

*N.* When the Moon is at *R* in her orbit, part of her enlightened ſide is turned away from the Earth; and ſhe appears gibbous again, as at *r.* When ſhe is at *T* (three quarters round her orbit from between the Earth and the Sun) half of her light and half of her dark ſide is toward the Earth; and ſhe appears half decreaſed, or in her third quarter, as at *t.* When ſhe is at *U* in her orbit, the greateſt part of her enlightened ſide is turned away from the Earth; and ſhe appears horned, as at *u.* And when he is between the Earth and the Sun again, as at *M*, ſhe is quite inviſible; becauſe the whole of her unenlightened ſide is then toward the Earth.

*E.* This does very well; but I like the candle and ball ſtill better.

*N.* For this very good reaſon, that they are more like the works of nature than any figures we can draw on paper.

*E.* How long is the Moon in going round her orbit from change to change?

*N.* Twenty-nine days, twelve hours, forty-four minutes, three ſeconds.

*E.* And what is her diſtance from the Earth's center?

*N.* Two hundred and forty thouſand Engliſh miles.

*E.* How many times would it take round the Earth, to go round the Moon's orbit?

*N.* Sixty times: and therefore, every degree of the Moon's orbit is equal in length to 60 degrees of a great circle (or 4155 miles) on the Earth's ſurface.

*E.* What is the Moon's diameter: and in what proportion is it to the Earth's?

*N.* The Moon's diameter is 2183½ miles; and it is in proportion to the Earth's diameter as 100 is to 365, or as 20 to 73.

*E.* What are thoſe ſpots which we ſee on the Moon ? I think I have heard ſome people ſay that they are ſeas.

*N.* So they were thought to be, before there were good teleſcopes to view the Moon by. But now they are found to be only darker places of the land in the Moon, which do not reflect the Sun's light ſo copiouſly as the whiter parts do. For we ſee they are full of pits and deep valleys : but if they were ſeas, they would have even and ſmooth ſurfaces.

*E.* So they certainly would, brother. But as it may be known by theſe ſpots whether the Moon turns round her own axis or not ;——if ſhe does turn round, I ſhould be glad to know in what time ; becauſe I ſhould thereby know the length of her days and nights.

*N.* She turns round her axis exactly in the time ſhe goes round her orbit ; and this we know by her keeping always the ſame ſide toward the Earth.

*E.* Then ſhe can have only one day and one night between change and change, or in 29 days, 12 hours, 44 minutes, 3 ſeconds, of our time.

*N.* Exactly ſo.

*E.* And is her axis inclined to her orbit, as our Earth's is to its orbit ?

*N.* No : her axis is perpendicular to the Ecliptic, in which the Earth moves ; and nearly perpendicular to her own orbit.

*E.* Then her days and nights muſt always be equally long ; and ſhe can have no different ſeaſons ?

*N.* You are very right, *Eudoſia.*

*E.* But pray, brother, how is it poſſible that we can only ſee one and the ſame ſide of the Moon, at all times, if ſhe turns round her axis ?——For I ſhould think, that if ſhe has ſuch a motion, we muſt ſee all her ſides.

*N.* Take up *that* little globe by its axis, between your fore finger and thumb.

*E.* There it is.

*N.* Now, hold its axis, without turning, (as you hold your pen when you write) and carry it round the ink-horn on the table.

*E.* I do.

*N.* And do you not ſee, that as you carry the globe ſo round, without turning it at all on its axis, all its ſides are ſucceſſively ſhewn to the ink-horn?

*E.* They are indeed.

*N.* Carry it round the ink-horn again; and try whether you can make it ſtill keep one and the ſame ſide toward the ink-horn, without turning round on its axis, by turning the axis round between your fore finger and thumb.

*E.* I find it impoſſible to do ſo:——for, in each revolution of the globe about the ink-horn, in order to make the globe keep ſtill the ſame ſide toward it, I am obliged to turn the axis once round betwixt my finger and thumb: and, as the axis is fixt in the globe, I cannot turn the axis round without turning the globe round too.

*N.* Well, ſiſter, ſeeing that the Moon goes round the Earth in her orbit, as you carry the globe round the ink-horn; is not her keeping the ſame ſide always toward the Earth a full proof of her turning round her axis?

*E.* It certainly is: and I can alſo ſee, that as the Sun is on the outſide of the Moon's orbit, her keeping always the ſame ſide toward the Earth, makes her ſhew herſelf all around to the Sun between change and change.——For, in the time that I carried the globe round the ink-horn, and kept always the ſame ſide toward it; you, who were on the out-ſide of the circle in which I carried the globe ſo round, ſaw all its ſides.

*N.* You are very right.——But I am ſorry to hear our breakfaſt-bell: for we have not yet done with the Moon.

◆

DIALOGUE

# DIALOGUE VII.

## *On the* MOON's *motion round the* EARTH and SUN; *and the* ECLIPSES *of the* SUN *and* MOON.

*Neander.*

SO, Siſter;——if yeſterday had not been Sunday, I believe you would not have given yourſelf *that* day's reſt from your aſtronomical ſtudies.

*Eudoſia.* To me, brother, theſe ſtudies are recreations, which I eſteem better than bare reſt.——And, on Sunday we reſt not; but are better employed in the duties of the day, than we generally are on all the other days of the week.

*N.* True; and therein our duty is cloſely connected with our intereſt.——Shall we now reſume our ſubject about the Moon ? as I told you, laſt Saturday morning, that we had not done with her.

*E.* If you pleaſe, Sir.

*N.* Then you muſt always ſtart the game ; and when *that* is done, we will purſue it.

*E.* I think the Moon would always appear full as ſeen from the Sun, if ſhe were big enough to be ſeen by an obſerver placed on the Sun's ſurface.

*N.* She certainly would ; becauſe, whichever ſide of her is turned toward the Sun at any time, *that* ſide would be fully enlightened by the Sun.

*E.* And I imagine, that if an obſerver were placed on the ſide of the Moon which always keeps toward the Earth, the Earth would appear to him in all the different ſhapes that the Moon does to us. Only, that when the Moon is *new* to us, the Earth would be *full* to the Moon ; and when the Moon is *full* to us, the Earth would diſappear, or be *new* to the Moon.

*N.* What reaſon have you for thinking ſo, *Eudoſia ?*

*E.* Becauſe, whichever ſide of the Earth or Moon is turned toward the Sun at any time, *that* ſide is then enlightened by the Sun. And therefore, when the dark ſide of the Moon *M* (*Fig.* 2. of PLATE IV.) is toward the Earth *E*, the enlightened ſide of the Earth is then fully toward the Moon ; and muſt appear to her like a great full Moon. And when the enlightened ſide of the Moon at *Q* is fully toward the Earth, the dark ſide of the Earth is toward the Moon ; and therefore it cannot appear to the Moon, as the Moon at *M* does not appear to us. And farther, when the Moon appears half full to us (or in her firſt quarter) at *O*, the Earth muſt appear half decreaſed to the Moon, being then half way between its full and change, as ſeen from her. And laſtly, when the Moon is in her third quarter at *T*, as ſeen from the Earth, the Earth muſt appear as in its firſt quarter to the Moon ; it being then the middle time between the new and full Earth, as ſeen from the Moon.

*N.* You are exactly right, ſiſter: and as the ſurface of the Earth is 13 times as large as the ſurface of the Moon; when the Earth is full to the Moon, its ſurface appears 13 times as big to the Moon, as the ſurface of the full Moon does to us.

*E.* If the Moon be inhabited on the ſide which always keeps toward the Earth, I think theſe inhabitants may as eaſily find their Longitude as we can find our Latitude.

*N.* Tell me how: and if you can make that out, I ſhall ſay you *think* very well.

*E.* When you explained the Longitude to me, you made me underſtand, that if there were a viſible meridian in the Heaven, keeping always over one and the ſame meridian on the Earth, (which it would do if it revolved eaſtward in 24 hours as the Earth does) the Longitude of any other meridian of the Earth from *that* meridian, might as eaſily be found as the elevation of the pole above the horizon is found.——Now, ſeeing that the Moon keeps always one and the ſame ſide toward the Earth, 'tis plain, that the Earth will be always over an obſerver's head who is on that part of the Moon's ſurface which ſeems to us to be her center. And therefore, if Longitude on the Moon were reckoned from the meridian of that obſerver, thoſe on all her other meridians on the ſame ſide, might find how many degrees lie between their meridian and that which is under the Earth, by obſerving how many degrees the Earth is Eaſt or Weſt of their meridian. But, as thoſe inhabitants who live on what we call the *back* of the Moon, never ſee the Earth; they are deprived of *that* eaſy method of finding their Longitude.

*N.* Truly, ſiſter, I ought to make you a very *fine ſpeech* for that thought: but having no talent that way, all I ſhall ſay is, that I am very well pleaſed by it.

*E.* I am very glad to hear you ſay ſo, becauſe you thereby aſſure me that I am right. — But now a difficulty occurs to my mind, which I beg you will remove.

*N.* Only tell it me; and I will remove it if I can.

*E.* The Moon goes round the Earth every month; and as the Earth goes round the Sun in a year, the Moon muſt do ſo too.——How happens it, that the Earth, by moving at the rate of 68,000 miles every hour, in its orbit, does not go off, and leave the Moon behind.

*N.* The Moon is within the ſphere of the Earth's attraction: and therefore, let the Earth move in its orbit as faſt as it will, the Moon muſt accompany it. For you know, that if you put a pebble into a fling, and whirl it round your head; the pebble will go round and round your head, whether you ſtand ſtill in one and the ſame place, or whether you walk directly forward, or go round the circumference of a large circle. And the tendency of the pebble to fly off, and the force with which you hold the ſtring to confine the pebble in its orbit, will be the ſame in one caſe as in the other.

*E.* I thank you, brother, for having ſet me right in this matter; and at the ſame time for convincing me, by the ſimile, that the Moon's centrifugal force, or tendency to fly out of her orbit, is equal to the power by which the Earth attracts her, and thereby retains her in her orbit: for, if her centrifugal force were greater than the Earth's attraction, ſhe would fly out of her orbit, and ſo abandon the Earth. And if her centrifugal force were leſs than the power by which the Earth attracts her, ſhe would come nearer and nearer the Earth in every revolution, and would fall upon it at laſt.

Pl. V.

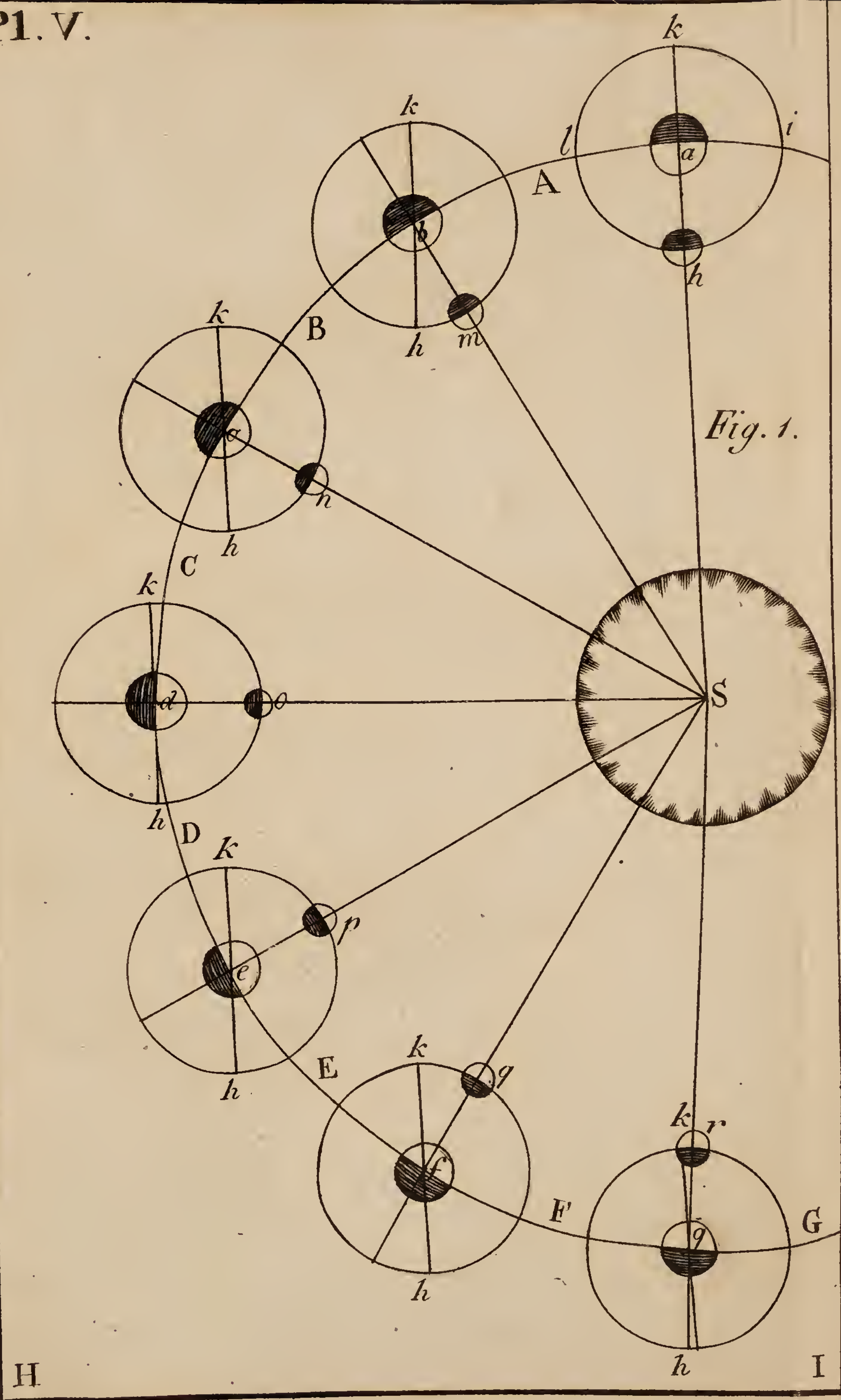

Fig. 1.

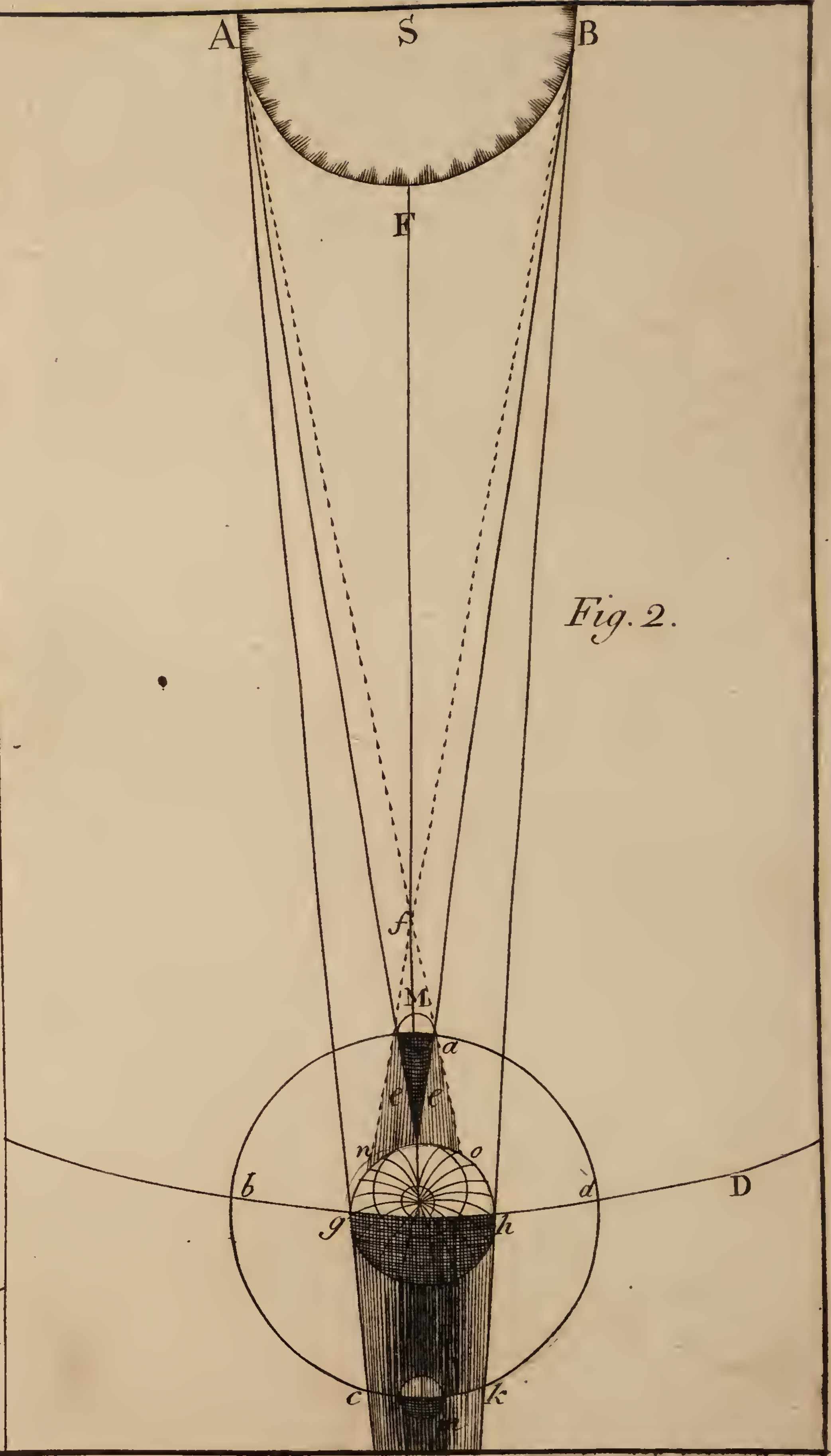

Fig. 2.

*N.* I find, dear *Eudoſia*, that you very ſeldom need to be ſet right: and when I do, you always improve upon it, by making farther obſervations.

*E.* By the laſt figure you explained, it would ſeem, that the Moon goes juſt round her orbit between change and change. But I think, that as both the Earth and Moon go round the Sun in a year, the Moon muſt not only go round her orbit between change and change, but even advance as many more degrees as the Earth has moved in its orbit during that time, in order to be again in conjunction with the Sun. For, in whatever part of the dial-plate of my watch, I find the hour and minute-hands in conjunction, I obſerve that the minute-hand muſt go as much more than round to the ſame point again, before it overtakes the hour-hand, as the hour-hand advances in the interval between its laſt conjunction with the minute-hand and its next.

*N.* You are very right; and your inference from the hour and minute-hands of the watch is full as good as mine from the pebble and ſling. I drew a figure, laſt Saturday afternoon, in order to explain this matter to you by it. But, as you underſtand the thing ſo well already, we have no occaſion for the figure.

*E.* Nay, brother; ——I beg you will ſhow me the figure, and explain it too, if your time will permit.

*N.* Then, here it is: ( PLATE V. *Fig.* 1. ) Let *ABCDEFG* be one half of the Earth's orbit; which will do as well for us, juſt now, as if the whole of it had been drawn. Let *S* be the Sun, *a* the Earth, *b* the Moon when new, or between the Earth and the Sun; and *i k l* the Moon's orbit, in which ſhe goes round the Earth according to the order of the letters *b i k l:* and let the Earth, together with the Moon and her (imaginary) orbit, go round the Sun in a year.

Draw a diameter *k b* of the Moon's orbit, when the Earth is at *a*; ſo as, if that line were continued, it would go on ſtraight to the Sun's center *S:* 'tis plain, that when the Moon is in the end *h* of *that* line, ſhe muſt be *new*, or between the Earth and the Sun.

As the Earth moves on, from *a* to *b*, from *b* to *c*, from *c* to *d*, from *d* to *e*, &c. the ſaid diameter *k h*, *k h*, *k h*, *k h*, will ſtill continue parallel to the poſition *k h*, that it had when the Earth was at *a*: that is, it will always keep perpendicular to the bottom-line *H I* of the plate. And therefore, if it pointed *once* toward a fixed ſtar, whoſe diſtance from the Sun is ſo great, that the whole diameter of the Earth's orbit bears no ſenſible proportion to that diſtance (which is really the caſe), the point *h* would *always* keep between the Earth and the ſame ſtar.

*E.* I underſtand you very well: but, do you ſay *The ſtars are fixed?*

*N.* I do ſay ſo; and will convince you afterward that *they are.*

*E.* I beg pardon for interrupting you ſo often.—— Pray, now proceed.

*N.* In the time the Moon goes round from *h* to *h* again, in the direction *h i k l h*, ſhe goes quite round her orbit; which ſhe would always do between change and change, if the Earth always remained at *a*.

But as the Earth advances as far in its orbit as from *a* to *b*, between any change of the Moon and the next that ſucceeds it; 'tis plain, that when the Earth is at *b*, and the Moon new at *m*, ſhe will have gone more than round her orbit from *h* to *h* again, by the ſpace *h m*. And as all circles, be they ever ſo great or ever ſo ſmall, contains 360 degrees (a degree being not limited by any certain number of miles, but by the length of the 360th part of a circle) the ſpace *h m*, by which the Moon has gone more than round her orbit, from her change at *h* to her change at *m*, will contain juſt as many degrees and parts of a degree, as the Earth has moved in that time, from *a* to *b* in its orbit.

At the ſecond change of the Moon from *h*, the Earth will be at *c*, and the Moon at *n*: by which time ſhe will have gone twice round her orbit from *h* to *h* again, and as much more as the ſpace or part *h n* of her orbit contains, which conſiſts of as many degrees as the part *a b c* of the Earth's orbit does.——And ſo on, through the whole figure.

*E.* I ſee all this very plainly; and that the figure includes ſix changes of the Moon, as from *h* to *m*, from *m* to *n*, from *n* to *o*, from *o* to *p*, from *p* to *q*, and from *q* to *r*. —— But, at the *laſt* of theſe changes, it ſeems (by the figure) that the Earth has not gone half way round the Sun: for the laſt line of conjunction *S r g* is not quite even with the firſt line of conjunction *a h S*.

*N.* Nor ſhould it be; for if it be rightly drawn (and I find I muſt take care how I draw figures for you), it muſt want 5 $\frac{1}{3}$ degrees of the Earth's progreſſive motion in half a year. For ſix courſes of the Moon, from change to change, contain only 177 days, 4 hours, 24 minutes, 18 ſeconds, which wants 5 days, 7 hours, 35 minutes, 42 ſeconds, of 182 days, 12 hours, which is the half of a common year. And, in that difference of time, the Earth moves ſomewhat more than 5 degrees in its orbit.

*E.* I remember you told me, that the time from change to change is 29 days, 12 hours, 44 minutes, 3 ſeconds; pray in what time does the Moon go round her orbit?

*N.* In 27 days, 7 hours, 43 minutes, 5 ſeconds.

*E.* And how far doth the Earth move in its orbit between change and change of the Moon?

*N.* Twenty-nine degrees, ſix minutes, twenty-five ſeconds. — And here you are to underſtand, that a minute is the 60th part of a degree, and a ſecond is the 60th part of a minute.

*E.* Then, 'tis plain, that between change and change, the Moon goes 29 degrees, 6 minutes, 25 ſeconds, more than round her orbit.

*N.* True,

*N.* True, *Eudoſia*; and now I have only to tell you farther, on this ſubject, that the Moon's *going round her orbit* is called *her periodical revolution*; and that her *going round from change to change* is called her *ſynodical revolution.*

*E.* I thank you, Sir, for having told me ſo much.—But are you not tired at preſent with hearing and anſwering my queſtions?

*N.* Very far from it:—I love theſe ſubjects; and my talking with *you* about them will keep *me* from forgetting them.

*E.* Then, I ſhould be exceeding glad to know ſomething about eclipſes.

*N.* You ſhall know *that* very ſoon.——In *Fig.* 2. of PLATE V. let *S* be the Sun, *M* the Moon, and *E* the Earth; *a b c d* the Moon's orbit, in which ſhe moves according to the order of the letters; and *C b d D* a part of the Earth's orbit, wherein it moves in the direction *C D.*—The Moon is new when ſhe is at *M*, and full when ſhe is at *m.*

Draw the ſtraight line *A e E* from the eaſtern edge of the Sun, cloſe by the eaſtern edge of the Moon, to the Earth *E*: then draw the ſtraight line *B e E* from the weſtern edge of the Sun, cloſe by the weſtern edge of the Moon, to the Earth *E.* Let theſe lines be ſuppoſed to turn round the middle line *F M E*; and the ſpace *e e*, within them, between the Moon and the Earth, will include the Moon's dark ſhadow, which is of a conical figure, (like an inverted ſugar-loaf) and covers only a ſmall part of the Earth's ſurface at *E*: and only from that ſmall part, the Sun will be quite hid by the Moon, and appear to be totally eclipſed; and it can be quite dark *only* at that part, becauſe the Moon ſtops not the whole of the Sun's light at that inſtant of time, from any other part of the Earth.——'Tis evident, that if the Moon were nearer the Earth, her dark ſhadow would cover a larger part of its ſurface; and if ſhe were farther from the Earth, her ſhadow would end in a point, ſhort of the Earth's ſurface; and then, ſhe could not hide the whole body of the Sun from any part of the Earth; and thoſe who were juſt under the point of the dark ſhadow, would ſee the edge of the Sun, like a fine luminous ring, all around the dark body of the Moon.

But, although the Moon can hide the whole body of the Sun, only from a ſmall part of the Earth, at any time, when the Sun appears to be thus eclipſed by the Moon; yet, in all ſuch eclipſes, the Moon hides more or leſs of the Sun from a very large portion of the Earth's ſurface. For,

Draw the ſtraight line *A f o* from the eaſtern edge of the Sun, cloſe by the weſtern edge of the Moon, to the Earth at *o*.——Then draw the ſtraight line *B f n* from the weſtern edge of the Sun, cloſe by the eaſtern edge of the Moon, to the Earth at *n*. Let theſe lines (*A f o* and *B f n*) be ſuppoſed to turn round the middle line *F M E*, and their ends (*n* and *o*) will deſcribe a large circle on the Earth's ſurface, around *E*; within the whole of which circle, the Sun will appear to be more or leſs eclipſed by the Moon at *M*, as the places within that circle are more or leſs diſtant from its center *E*, where the dark ſhadow falls. For, when the Moon is at *M*, an obſerver on the Earth at *n*, will ſee the eaſtern edge of the Moon, juſt, as it were, touching the weſtern edge of the Sun at *B*; and an obſerver at *o* will ſee the weſtern edge of the Moon, juſt, as it were, touching the eaſtern edge of the Sun: but to all the places between *n* and *o*, the Moon will hide a part, or the whole of the Sun, according as they lie between *n* and *E*, or between *o* and *E*, or directly at *E*. ——This faint ſhadow, all around the dark one, from *n* to *o*, on the

Earth's ſurface, is called the *Penumbra*, or partial ſhadow of the Moon.

*E.* How many miles are contained in the diameter of the circle which the Penumbra fills, on the Earth's ſurface?

*N.* About 4700, when its center falls directly in a right line from the Sun's center to the Earth's, at a mean rate.——But when the Penumbra falls obliquely on the Earth's ſurface, its figure thereon will be elliptical; and then, the ſpace that it covers will be much larger; eſpecially if the Moon be then at her leaſt diſtance from the Earth.

*E.* What! brother: is not the Moon's diſtance from the Earth always the ſame?

*N.* By no means: for the Moon's orbit is of an elliptical (or oval) figure; and every ellipſis has two centers, which are between the middle and the ends of its longeſt diameter: and the Earth's center is in one of the centers (or, *as they are called*, focuſes) of the Moon's elliptical orbit.——So that, when I formerly told you, that the Moon's diſtance from the Earth's center is 240,000 miles, I only meant her *mean* (or middle) *diſtance* between her greateſt and leaſt diſtances.

*E.* Then I underſtand, that the Moon's diſtance from the Earth muſt be continually changing.——But ſuppoſing the Sun to be eclipſed when the Moon is at her leaſt diſtance from the Earth; what is the diameter of the ſpot upon the Earth's ſurface that would be quite covered by the Moon's dark ſhadow; from all parts of which ſpot, the Sun would be totally hid by the Moon?

*N.* About 180 miles.

*E.* As the Moon's diſtance from the Earth is little more than a 396th part of the Sun's diſtance from it, (as I have computed) I ſuppoſe the Moon's ſhadow at the Earth will move almoſt as faſt as the Moon moves in her orbit.——Pray, in what time will the dark part of the ſhadow move over about 180 miles of the Earth's ſurface?

*N.* In four minutes and an half: and would go over *that* ſpace ſooner, if the Earth's motion round its axis (which is eaſtward, and conſequently the ſame way that the Moon's ſhadow goes over the Earth) did not keep the place on which the ſhadow falls, longer in the ſhadow than it would be, if the Earth had no ſuch motion.

*E.* Then an eclipſe of the Sun can never continue total, above four minutes and an half, at any place of the Earth?

*N.* It never can, even when it falls on the Equator, where the parts of the Earth's ſurface move the quickeſt of all. And when it falls upon any part of Britain, whoſe motion is ſlower, becauſe it is nearer the motionleſs pole, it would be ſooner over.

*E.* How then could the Sun be darkned ſo long as three hours, at the time of our SAVIOUR's crucifixion, as it is mentioned to be in the Goſpels?

*N.* There is no way of accounting for *that* darkneſs, upon aſtronomical principles: for it was entirely out of the common courſe of nature.

*E.* How do you prove that it was out of the common courſe of nature?

*N.* Becauſe our Saviour was crucified on a full Moon day; and then, the Moon being oppoſite to the Sun, could not poſſibly hide the Sun from any part of the Earth.

*E.* I ſhould be very glad to know how you can prove, that the crucifixion was on a full Moon day.

*N.* Becauſe it was at the time of the Paſſover: and the Paſſover was always kept at the time of full Moon.

*E.* You have made this very clear.——And now, if you pleaſe, I ſhould be glad to have the cauſe of the Moon's eclipſes explained.

*N.* In the ſame figure, draw the ſtraight line *A g c* from the eaſtern edge of the Sun, cloſe by the eaſtern edge of the Earth at *g*; and the ſtraight line *B h k* from the weſtern edge of the Sun, cloſe by the weſtern edge of the Earth at *k*.—Let theſe two lines be ſuppoſed to turn round the middle line *F M m*, and they will include the ſpace between the part which is filled by the Earth's ſhadow *g c k h*.——'Tis plain, that when the Moon is at *m* in her orbit, ſhe is totally covered by the Earth's ſhadow, and eclipſed by it; as it muſt then fall upon her, becauſe the Earth is between her and the Sun.

*E.* But how is it, that the Moon is at all viſible, when the Earth muſt entirely ſtop the Sun's light from falling upon her, and ſhe has no light of her own? For, the ſame ſide of the Moon that is toward the Earth at her change, is alſo toward the Earth at her full.——And, as we cannot ſee her at the change, I ſhould think we could not ſee her when ſhe is totally eclipſed; becauſe *that* ſide of her which is dark in the former caſe, when the Sun cannot ſhine upon it, ſhould be as dark in the latter, when the Earth intercepts the Sun's rays from it.——But the Moon was very viſible in her laſt total eclipſe; for I ſaw her, and ſhe appeared of a colour ſomewhat like that of tarniſhed copper.

*N.* You are very ſhrewd in your remarks, ſiſter:—and I will tell you why the Moon is not inviſible when ſhe is totally eclipſed.

The air, or atmoſphere, which ſurrounds the Earth, to the height of about 47 miles, is the cauſe of this. For, all the rays of the Sun's light which paſs through the atmoſphere, all around the Earth, in the boundary *(g h)* of light and darkneſs, are, by the atmoſphere, bent inward, toward the middle of the Earth's ſhadow:

and thoſe rays, ſo mixed with the ſhadow, fall upon the Moon, and do enlighten her in ſome ſmall degree. She reflects the rays back to the Earth which fall upon her, and ſo ſhe is viſible *only* on that account. For, if the Earth had no atmoſphere, its ſhadow would be quite dark; and the Moon would be as inviſible, when ſhe is totally immerſed therein, as ſhe is at the time of her change.

*E*. I thank you, brother, for all theſe informations; but I ſtill want more.

*N*. Only ſay what they are; and I will inform you if I can.

*E*. I ſee plainly by the figure, that the Sun can never be eclipſed (in a natural way) but at the time of new Moon; becauſe the Moon's ſhadow cannot fall upon the Earth at any other time: and that the Moon can never be eclipſed but when ſhe is full; becauſe that is the only time when the Earth's ſhadow can fall upon her. But though we have a new and a full Moon in every month of the year, I find my almanack mentions but very few eclipſes; and generally, about half a year between the times of their happening.

*N*. If the Moon's orbit *a b c k d a* lay exactly even (or in the ſame plane) with the Earth's orbit *C b d D*, as it is drawn on the flat paper, the Sun would be eclipſed at the time of every new Moon, and the Moon at the time of every full. But one half of the Moon's orbit lies on the North-ſide of the plane of the Earth's orbit, and the other half on the South-ſide of it: and conſequently, the Moon's orbit only croſſes the Earth's orbit in two oppoſite points ——When either of theſe points are between the Earth and the Sun, or nearly ſo, at the time of new or full Moon, the Sun or Moon will be eclipſed accordingly. But, at all other new Moons, the Moon either paſſeth above or below the Sun, as ſeen from the Earth: and, at all other full Moons, the

Moon either paſſeth above or below the Earth's ſhadow. One of theſe points is called *the Aſcending Node* of the Moon's orbit; becauſe, when the Moon has paſt by it, ſhe aſcends northward, or to us, above the plane of the Earth's orbit; and the oppoſite point is called *the Deſcending Node* of the Moon's orbit; becauſe, as ſoon as ſhe has paſt by it, ſhe deſcends ſouthward; which, to us in the northern parts of the Earth, is below the plane of the Earth's orbit.

*E.* Suppoſing that either of theſe nodes were between the Earth and the Sun juſt now; how much time would elapſe before the other could be ſo?

*N.* It would be juſt half a year, if a line drawn from the one to the other kept always parallel to its preſent poſition (like the above-mentioned diameter of the Moon's orbit, *k h*, in *Fig.* 1.): but the nodes move backward, or toward the Weſt, contrary to the Moon's motion eaſtward in her orbit, at the rate of 19⅓ degrees every year.——So that, from the time of the Sun's being in conjunction with either of the Moon's nodes, to the time of his being in conjunction with the other, is only 173 days, 7 hours, 3 minutes.

*E.* As there muſt be *ſome* diſtances from theſe nodes, within which the Sun and Moon muſt be eclipſed; I ſhould be glad to know what theſe diſtances are?

*N.* They are only 17 degrees for the Sun, and 12 for the Moon.

*E.* Now, let me ſee.——The Moon's whole orbit contains 360 degrees; of which there are only 17 on each ſide of each node, within which the Sun may be eclipſed. Twice 17 is 34, about one node, and there are as many about the other: in all, 68 degrees out of 360, for eclipſes of the Sun. And, as there are 12 degrees on each ſide of each node, within which the Moon can be eclipſed; there muſt be no more than 48 degrees in all out of the whole 360, for the eclipſes of the Moon. Am I right, brother? If I am, 'tis no wonder that we ſhould have ſo many new and full Moons, and ſo few eclipſes.

*N.* You are quite right, *Eudoſia*; and I am very glad to find that you make ſuch a quick progreſs.

*E.* I know that the times of eclipſes may be calculated before-hand, becauſe I ſee they are always predicted in the almanacks. Can you calculate them?

*N.* Yes.

*E.* I wiſh you would teach me to do ſo too, if you think I have a ſufficient capacity for that branch of ſcience.

*N.* You have much more; and I will inſtruct you with pleaſure; for you have not only learnt the four common rules of arithmetic, but even as far as the Rule of Three.——And, in theſe calculations, no farther arithmetic is neceſſary than *addition* and *ſubtraction*. But you muſt learn firſt to calculate the times of new and full Moons.

*E.* That I will do, with very great pleaſure.

*N.* Then we will ſet about it to-morrow morning, if you pleaſe: but the whole will take up a week at leaſt: during which time, we muſt ſuſpend our uſual confabulations.

*E.* I wiſh *to-morrow* were come already.

*N.* You remember the book which you ſaw, a few days ago, in this room; in which you told me you had taken notice of ſomething concerning the Ecliptic and its ſigns.——Did you look at the title-page of that book?

*E.* I remember the book very well; but did not look at the title-page.

*N.* It is *Ferguſon*'s Aſtronomy. I ſent for it to Mr. *Cadell*'s ſhop, in the Strand, oppoſite Catharine-ſtreet, on purpoſe to make you a preſent of it. There it is;

and I am ſure you are qualified to read and underſtand it.

*E.* I heartily thank you, dear *Neander*, for this preſent.

*N.* There are in it plain and eaſy tables and precepts for calculating the true times of new and full Moons and eclipſes. And, if you have any ſpare time to-day, I wiſh you would begin, by yourſelf, to read the precepts, and compare them with the tables, and with the examples of calculation. And then, if you find any thing difficult, mark it; and I will help you out to-morrow morning. Mean time, if there be any thing elſe, which you would have us to talk about, before we are called to breaſtfaſt, which is later than uſual to day) tell me what it is.

*E.* I wiſh I underſtood the cauſe of the ebbing and flowing of the Sea. But now the bell begins to ring for us.

*N.* Very well. — Be here in about an hour after breakfaſt.

* * *

DIALOGUE

Pl. VI.

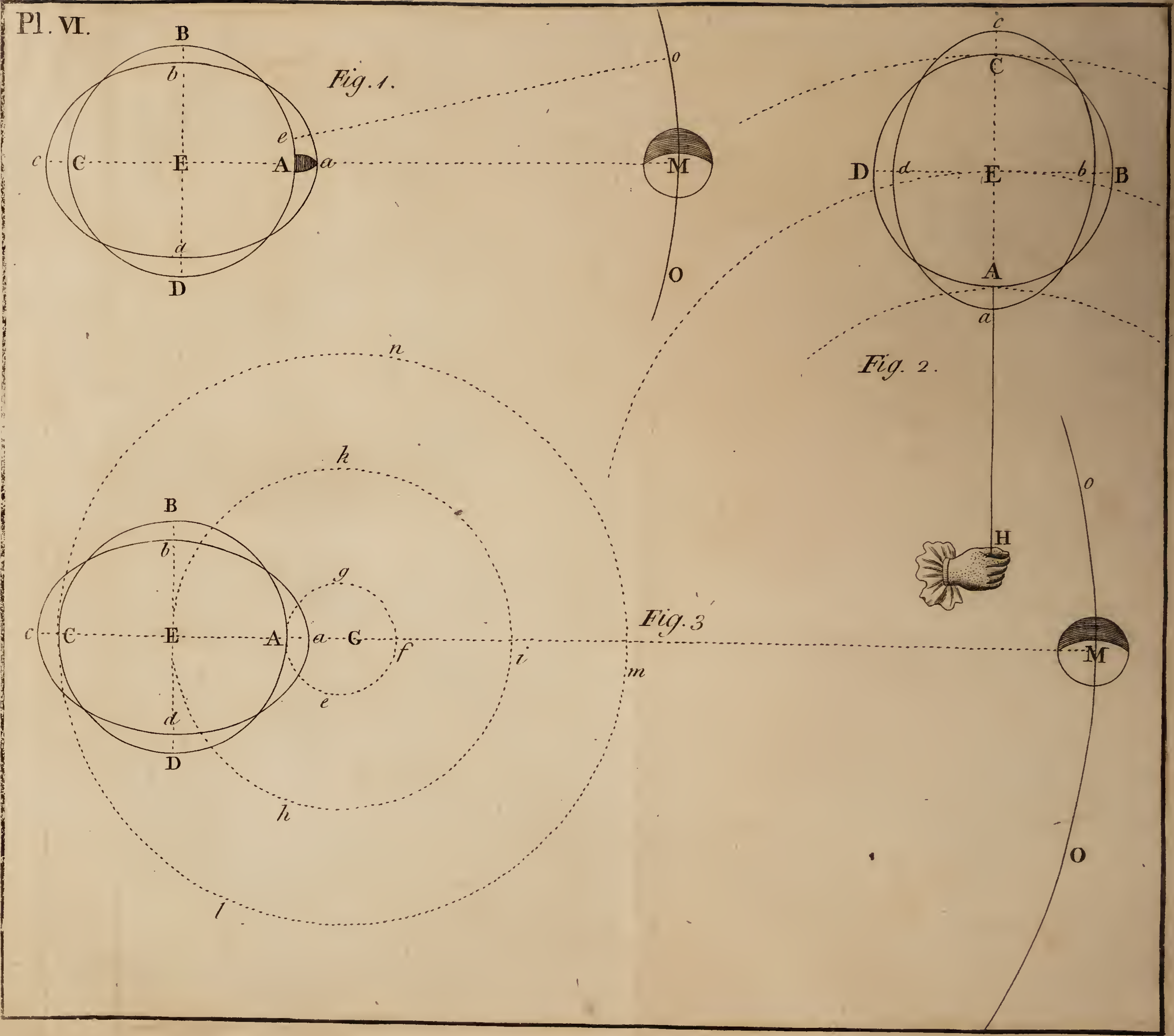
Fig. 1.
B
b
c
C
E
A
a
e
o
M
O
d
D
Fig. 2.
c
C
D
d
E
b
B
A
a
H
o
M
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Fig. 3
B
b
c
C
E
A
a
G
f
g
e
k
h
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# DIALOGUE VIII.

## *On the* CAUSE *of the* EBBING *and* FLOWING *of the* SEA.

*Neander.*

YOU are very punctual, ſiſter.——I have drawn out ſome figures for you ſince breakfaſt; and, juſt as you entered the room, I was putting the laſt letter of reference to them. Here they are.

*Eudoſia.* I thank you, brother; and do ſuppoſe that, by theſe figures, you intend to explain the cauſe of the ebbing and flowing of the Sea.

*N.* I do.——In *Fig.* 1. of PLATE VI. let *ABCDA* be the Earth, all covered with water except the top of an iſland *A a.* Let the Earth be in conſtant motion, turning eaſtward round its center *E*, every 24 hours, according to the order of the letters *ABCD*; and let *M* be the Moon, moving eaſtward in her orbit *O o*, as from *M* to *o* in 24 hours, 50 minutes. You know that the Earth and Moon are within the reach of each other's attraction; and therefore, as the Earth attracts the Moon, ſo the Moon re-attracts the Earth.

*E.* Yes, Sir.

*N.* Do you remember my telling you, ſome days ago, that the attraction diminiſhes, as the ſquare of the diſtance from the attracting body increaſes?

*E.* I remember it very well.

*N.* Then you know, that the Moon muſt attract the ſide *A* of the Earth which is neareſt to her (at any time) with a greater degree of force than ſhe attracts the Earth's center *E*; and that ſhe attracts the center *E* with a greater degree of force than ſhe attracts the ſide *C* of the Earth, which is then fartheſt from her.

*E.* Certainly.

*N.* And that the Earth and Moon would fall towards one another, by the power of their mutual attractions, if there was nothing to hinder them: and that the Moon would fall as much faſter toward the Earth than the Earth would fall toward the Moon, as the quantity of matter in the Earth is greater than the quantity of matter in the Moon.

*E.* Undoubtedly ſo; becauſe every particle of matter attracts with an equal degree of force; and therefore, the body which has the greater quantity of matter muſt attract the other with ſo much the greater degree of force.

*N.* Well done, *Eudoſia.* Let us now ſuppoſe the Earth and Moon falling toward each other. The earthy parts of our globe being connected, and cohering together, would not yield to any difference of the Moon's attractive force; but would all move equally faſt toward the Moon : as if a cord were tied to each end of a great folio book on the table, and you ſhould pull one cord with the force of four pounds, and I pull the other cord the ſame way with the force of eight pounds, ſo as to move the book ; all the parts of it will move equally faſt, notwithſtanding the different forces by which you and I pull it. But the waters are of a yielding nature ; the coherence of their particles being very ſmall : and therefore, they will be differently affected, according to the different degrees of the Moon's attractive force, at different diſtances from her.

And therefore, as the waters at *A* are more attracted by the Moon than the Earth is at its center *E*, they move faſter toward the Moon than the Earth's center does ; and conſequently, with reſpect to the Earth's center, they riſe higher toward the Moon, as from *A* to *a* : and as the center *E* moves faſter toward the Moon than the waters on its ſurface at *C* do ; the waters at *C* will be, as it were, left behind : and conſequently, with reſpect to the center *E*, they will be raiſed, as from *C* to *c*.

*E.* So far, I underſtand you perfectly well.

*N.* But as there is ſtill the ſame quantity of water on the whole Earth, the waters cannot riſe at one place without falling at another.——And therefore, the waters muſt fall as low at *b* and *d* as they riſe, at the ſame time, at *a* and *c* : ſo that an obſerver placed over *E*, at a diſtance from the Earth, would ſee the ſurface of the waters not of the round ſhape *ABCD*, as they would be if the Moon did not diſturb them by her attraction, but of the elliptical ſhape *a b c d*.

Then, as the Earth turns eaſtward round its axis, 'tis plain, that when the iſland *A a* is at *A*, it will be in the *high water*, under the Moon *M*: when it is at *B*, it will be in the *low water*, ſix hours from under the Moon : when it is at *C*, it will be in the *high water* again, twelve hours from under the Moon: and when it is at *D*, eighteen hours from being laſt under the Moon, it will be in the *low water* again. So that, if the Moon had no progreſſive motion in her orbit *O o*, but kept always in the ſame right line *A M*, the iſland *A a* would have two ebbings and two flowings of the Sea every 24 hours.

*E.* It would. But I find the tides are put down, in my almanack, later every day than on the day before. And now, I apprehend the reaſon of this to be, that as the Moon goes eaſtward round her orbit in a month, and the Earth turns eaſtward round its axis every 24 hours; the Moon makes *part* of a revolution in the time that the Earth makes *a whole* rotation: and therefore, the Earth muſt turn as much more than round its axis, before the ſame iſland can come even with the Moon again, as the Moon has advanced in her orbit during that interval of time.

*N.* You are right *Eudoſia*:——for, in the time of the iſland's revolving from *A* to *A* again (in the direction *ABCDA*) which is 24 hours; the Moon moves from *M* almoſt to *o* in her orbit: and therefore, after the iſland has come round to *A* again, it muſt move on from *A* to *e*, before it can be in the middle of the tide of flood the next day, under the Moon, which will have then moved from *A* to *o*.

*E.* How long is the iſland in moving from *A* to *e*?

*N.* Full 50 minutes: and ſo much later are the tides every day than they were on the day before. The ſailors call it only 48 minutes; and it would be exactly ſo, if the Moon were 30 compleat days and nights in going round from change to change. But as the time is only 29 days, 12 hours, 44 minutes, 3 ſeconds, (at a mean rate) ſhe muſt move a little farther every day than ſhe would if ſhe took the full 30 days: and this difference is equal to about 2 minutes of time, of the Earth's motion on its axis.

*E.* Then as the Moon goes round her orbit, from change to change, in 29½ days (in round numbers) the iſland *A a* can only come 28½ times round from the Moon to the Moon again, in that time; and conſequently, it can have no more than twice that number of tides of flood, at *a* and *c*; or 57 tides of flood, and as many of ebb, between change and change of the Moon.

*N.* You are very right: and conſequently, in two courſes of the Moon, from change to change, which is 59 days, 1 hour, 28 minutes, 6 ſeconds, there are only 57 double tides of flood and as many of ebb.

*E.* This account of the tides would be extremely natural, and eaſy to be underſtood, if the Earth and Moon were continually falling toward one another. But ſeeing that the Moon's motion in her orbit gives her a centrifugal force, equal to the force with which the Earth attracts her, ſhe cannot fall toward the Earth at all. And, from what you told me, in our ſecond dialogue, about the Earth and the Sun; I ſhould think, that if the Earth itſelf did not deſcribe a ſmall orbit round the common center of gravity between it and the Moon, in the time the Moon goes round her orbit, the Moon's attraction would take the Earth away, as it could have no centrifugal force to balance her attraction.

*N.* Dear ſiſter, you cannot imagine how much pleaſure it gives me to talk with you on theſe ſubjects; on account of the proper inferences and applications you make.——The Earth and Moon do really move round the common center of gravity between them, every month: and it is *that* center of gravity that deſcribes the very orbit in which the Earth's center would move round the Sun in a year, if the Earth had no Moon to attend it.

*E.* You may thank yourſelf, *Neander*, for all thoſe inferences and applications; as they only reſult from your explanations, and leading me ſo gradually on, from one ſubject to another.——But, pray how many miles is it from the Earth's center to the common center of gravity between the Earth and Moon? Undoubtedly, *that* diſtance, compared with the Moon's diſtance from the Earth's center, muſt be in proportion to the quantity of matter in the Moon compared with the quantity of matter in the Earth.——If you will tell me how much greater the quantity of matter in the Earth is than the quantity of matter in the Moon, I will try to compute how far the common center of gravity between them is from the Earth's center.

*N.* The Earth's quantity of matter is 40 times as great as the Moon's.

*E.* Very well.—— And the Moon's mean diſtance from the Earth's center is 240,000 miles.——Now, I divide 240,000 by 40, and the quotient is 6000; which I think, muſt be the diſtance of the common center of gravity between the Earth and Moon, from the Earth's center: and, that the ſaid common center of gravity muſt always be in a right line between the centers of the Earth and Moon; becauſe both theſe bodies move round it.—Am I right, brother?

*N.* Indeed you are: and, before we talk further about the common center of gravity between the Earth and the Moon, I will endeavour to illuſtrate this affair about the tides to you in a different manner from what I have done. For I find, that even if I had intended to explain it by the falling of the Earth and Moon toward each other, you would have juſtly believed that I was miſleading you.

Here is a circular hoop (*Fig.* 2.) *A B C D*, of thin plate braſs.——You ſee it is very flexible: for, as I pull out the parts *A* and *C* to *a* and *c*, the parts *B* and *D* fall in to *b* and *d*; and the hoop becomes of the elliptical ſhape *a b c d*.

*E.* True; —— and juſt like the ſhape of the ſurface *a b c d* of the water, (in *Fig.* 1.) as affected by the Moon's attraction.

*N.* But, if I quit my hold of the hoop at *a* and *c*, it will return to its former circular ſhape *ABCD*.

*E.* I ſee it does, now you have left it at liberty.

*N.* And, if the Moon's attraction ſhould ceaſe (*Fig.* 1.) the waters *a b c d* would return, from their elliptical ſhape *a b c d*, to their former round ſhape *A B C D*.

*E.* Yes; for they would run from the higheſt parts *a* and *c* to the loweſt parts *b* and *d*, till their ſurface was equally diſtant from the Earth's center *E*, all around.

*N.* Now, I tie the end *A* (*Fig.* 2.) of the ſtring *AH* to any part, as *A*, of the circular hoop *ABCD*, and take hold of the other end *H* of the ſtring with my hand. If I whirl the hoop round my head like a ſling, what do you think will happen?

*E.* Why; the hoop will endeavour to fly off, as a pebble in a ſling would do.

*N.* True; but do you think that all the parts of the hoop will then have an equal tendency to fly off?

*E.* Let me conſider.——I think they will not. For as the part *C* will go round your head in the ſame time as the part *A*, but faſter, becauſe it is further diſtant from your hand; I imagine, that the part *C* will have as much more tendency to fly off than the part *A* has, as its diſtance from your hand is greater.

*N.* Exactly ſo, becauſe it will move ſo much faſter, as the circle it deſcribes is larger. Now obſerve, I whirl it round my head. What ſhape is it *now* of?

*E.* It is of the elliptical ſhape *a b c d.*

*N.* Yes, for the tightneſs of the ſtring draws out the ſide next my hand, from *A* to *a*; and the centrifugal force of the other ſide throws it out as far, from *C* to *c*. And now, if an inflexible circular ring (like the rigid Earth) *A B C D* ſhould lie upon the elliptical hoop *a b c d*, and turn 29 times and a half round the center *E*, in the time the hoop and circle were moved once round my head; would not any point, as *A*, of the circular ring, come ſucceſſively even with the higheſt parts *a* and *c* of the elliptical hoop, and with the loweſt parts *b* and *d* of it; as the Iſland *A a* (*Fig.* 1.) comes to the high water at *a* and *b*, and the low water at *c* and *d*, by the Earth's motion on its axis?

*E.* It would. And I think that *Fig.* 3. is ſomewhat analogous to *Fig.* 2.

*N.* It is very much ſo; and now is the proper time to explain *Fig.* 3.

Let *A B C D* be the Earth, *M* the Moon, *O o* the Moon's orbit, and *G* the common center of gravity between the Earth and the Moon, round which both theſe bodies move, once a month; the Moon in the direction *O o*, and the Earth in the direction *E h.* By this motion, all the parts of the Earth will have a centrifugal force, or tendency to fly off in or parallel to the line *A E C*: and the centrifugal force of each part will be directly in proportion to its diſtance from the common center of gravity *G*; becauſe the ſpaces through which theſe parts move, will be reſpectively as their diſtance from *G*; that is, as the ſemidiameters of thoſe circles which they all deſcribe in the ſame period of time. Thus, the centrifugal force of the point *A* will be as the line *A G*; the centrifugal force of the center *E* will be as the line *EG*; and the centrifugal force of the point *C* will be as the line *C G*: for the point *A* deſcribes the ſmall circle *A e f G A* in the time the point *E* deſcribes the larger circle

*E h i*

*E h i k* , and in the time the point *C* deſcribes the ſtill larger circle *C l m n C*; which is in a month; and in that time, the Moon goes round her orbit *O o*.

The Moon's attraction at the Earth's center *E* exactly balances the Earth's centrifugal force at *E*; and conſequently retains the center *E* in the orbit *E h i k E*. But her attraction at *A* is greater than *E*, and leſs at *C* than at *E*. So that where the Moon's attraction is greateſt, as at *A*, the centrifugal force is leaſt: and therefore, the exceſs of attraction cauſeth the waters to riſe, as from *A* to *a*, on the ſide of the Earth which is at any time neareſt the Moon *M*. But, at *C* (the ſide which is then fartheſt from the Moon) the attraction is leaſt, and the centrifugal force greateſt: and therefore, the waters will riſe as high from *C* to *c*, by the exceſs of the centrifugal force there, as they riſe on the oppoſite ſide from *A* to *a* by the exceſs of the Moon's attraction. Are you ſatisfied now, *Eudoſia?*

*E.* I was ſadly afraid, that the riſing of the tides on the ſide of the Earth which (at any time, by its motion on its axis) is turned away from the Moon, would be very difficult to account for. But you have made it juſt as plain, that they muſt riſe as high on the ſide of the Earth which is oppoſite to the Moon, as they do on the ſide which is under the Moon. Did you ever ſee this confirmed by an experiment?

*N.* Yes; I have ſeen Mr. *Ferguſon* do it, to the ſatisfaction of every obſerver, by a plain experiment in one of his machines, called the *Whirling Table*; and he is the firſt that ever did ſo. He has given a full account of it in his Lectures on *Mechanics*, *Hydroſtatics*, *Pneumatics*, *Optics*, with *the Uſe of the Globes*, and *the Art of Dialing*. In that book, there are plates of all his machines for the above purpoſes. I ſhall ſend for it from Mr. *Cadell's* ſhop to-morrow, and make you a preſent of it, on account of the quick progreſs you have made in aſtronomy: and then you can by yourſelf, learn a courſe of experimental philoſophy.

*E.* Indeed, brother, you lay me under ſo many obligations, that I ſhall never be able to make you any proper return for them. But there is one thing, that I had almoſt forgot to aſk you. Pray, what is meant by the *ſpring* and *neap tides?*

*N.* The Earth is ſo ſmall, in compariſon of its diſtance from the Sun, that the Sun's attractive force is nearly equal on all parts of the Earth: and therefore, there can be but little difference between the centrifugal force on the ſide of it which is next the Sun, and the centrifugal force on the oppoſite ſide. But ſtill there is ſome difference, as the Earth moves on its orbit. And therefore, if the Earth had no Moon to attend it, there would be *ſmall tides* occaſioned by the Sun. Conſequently, when the Sun, Moon, and Earth are all in a right line (which they are at the time both of new and full Moon) their joint actions concur; and ſo, raiſe the tides higher at theſe times than at any other: and this is called the *Spring Tides.* But, when the Moon is in her quarters, her action on the tides is *croſs-wiſe* to the Sun's; for then the Sun is in a line with the *low-water*, and his action keeps the tide from falling ſo low there, and conſequently from riſing ſo high under and oppoſite to the Moon, as they would do by the action of the Moon, if the Sun did not diſturb them at all; and this is called *the neap Tides.*

*E.* I underſtand you very well; and do ſee plainly, that a ſtraight line drawn from the Moon's center through the Earth's center, would be in the higheſt part of the tides on both ſides of the Earth.

*N.* You are a little miſtaken in that point, *Eudoſia*; which may be owing to its being ſo repreſented in the figures. But, I am ſure you would not have been ſo, if you had remembred what I told you in our firſt Dialogue; namely, that all bodies which are put into a ſtate of motion will perſevere in that motion, till ſomething ſtops their courſe. If you put water into a baſon, and give it a little ſhake, and then ſettle the baſon ſuddenly; the water will riſe a little further, on the ſide to which you gave it the motion, after the baſon is ſettled again, than it did in the inſtant when you ſettled it. Pray, have you forgot your fall in the boat, when it ſtruck againſt the bank of the river?

*E.* I have not, brother; and the inference is plain.

*N.* It is: and therefore you know, that when the waters are put into a riſing ſtate of motion by the action of the Moon; they would riſe a little higher, if the Moon were annihilated at the inſtant of her being on the meridian, even of a place where ſhe was directly over head. But you are ſtill to conſider farther, that although the Moon's attraction at any place is greateſt when ſhe is on the meridian of that place, becauſe ſhe is then the neareſt that ſhe can be to the place on that day; yet her attraction at the place does not then ceaſe, but continues for ſome time after ſhe has paſt the meridian: and this continuance of attraction, tho' weaker, will cauſe the waters to keep on in their riſing ſtate, till the attraction juſt balances the tendency of the waters to fall back again.

*E.* I thank you, brother, for ſetting me right. But, pray, how long is the Moon paſt the meridian when the water is at the higheſt?

*N.* If the Earth was covered all over with water, ſo as the two eminences of the tides at *a* and *c* might regularly follow the Moon; ſhe would always be three hours paſt the meridian of any given place, when the tide was at the higheſt at that place. But, as the Earth is not all covered with water, and the different capes and corners of the land run out all manner of ways into the oceans and ſeas: the regular courſe of the tides is much interrupted thereby; and alſo by their running through ſhoals and channels. So that, at different places, the tides are higheſt at very different diſtances of the Moon from the meridian. But, at whatever diſtance the Moon is from the meridian, on any given day, *at any place*, when the tide is at its height *there*; it will be ſo again on the next day, much about the time when the Moon is at the like diſtance from the meridian again.

*E.* You have quite ſatisfied me about the tides: and now I will go to my room, and ſtudy *Ferguſon*'s method of calculating the times of new and full Moons.

◆

# DIALOGUE IX.

## *On the fixed* STARS, *and* SOLAR *and* SYDEREAL TIME.

*Neander.*

WHAT is the matter, ſiſter? —— Surely you could not have gone to your room and returned, ſince you left me.

*Eudoſia.* I had ſcarce gone out of *this* room, when ſomething came into my mind, which was, that you promiſed me, ſome days ago, to demonſtrate that all the Stars are at reſt.——And leaſt I ſhould forget it again, I now beg leave to re-mind you of it, if you have leiſure at preſent.

*N.* For *that,* I refer you to *Ferguſon*'s aſtronomy: and, before you have read the firſt three chapters, you will not only be convinced that all the Stars are at reſt; but alſo that they are Suns to innumerable ſyſtems of planetary worlds, as our Sun is to its own ſyſtem of planets.

*E.* What! other Sun's, and planetary worlds belonging to them! You amaze me!

*N.* The Deity is infinite in all his perfections: and as he has power enough to create and place Suns and worlds throughout the whole infinitude of ſpace, ſo he has goodneſs enough to induce him to do it. But now, if you pleaſe, I will tell you of ſomething which I did not think of before; namely, to inform you of the difference between *Solar* and *Sydereal time.*

*E.* You ſpeak too learnedly for me juſt now, brother; and it is the firſt time you ever did ſo.

*N.* Solar time is the time meaſured by the Sun's apparent motion round the Earth; and Sydereal time is the time meaſured by the Stars in *their* apparent motion round it.

*E.* Now I underſtand you; and have often obſerved, that if any Star be ſeen, juſt as if it were over a neighbouring chimney, at any hour of the night; in a week afterward, the ſame Star is ſooner ſeen over the ſame chimney.

*N.* True: and in 365 days, the ſtars ſeem to have made 366 revolutions about the Earth; ſo that they gain one hour every 24th part of the year upon the time ſhewn by a well regulated clock. And therefore, every Star comes almoſt four minutes ſooner to the meridian, every ſucceeding day or night, than it did on the day or night before. The real difference is 3 minutes 55 ſeconds and 54 ſixtieth parts of a ſecond. So that, if one clock ſhould be ſo well regulated as to ſhew the time to be XII at noon this day, and on the 365th day afterward; and another clock ſhould be ſo regulated as to ſhew the time to be XII every day or night when any given Star is on the meridian; the latter clock would gain 3 minutes 55 ſeconds and 54 ſixtieth parts of a ſecond upon the former, in each revolution of the ſame Star to the meridian.

*E.* What is the reaſon of *this?*

*N.* Much the ſame as *that* of the Moon's going round her orbit in leſs time than ſhe goes round from change to change, or from between the Earth and the Sun to the ſame poſition again: as I explained to you, by *Fig.* 1. of PLATE V. laſt Monday morning, in our Seventh Dialogue: and we may make the ſame figure do for the preſent ſubject. You remember I told you that the whole diameter of the Earth's orbit is but as a point, in compariſon to the diſtance of the Stars; which is the ſame as to ſay, that a globe of 190 millions of miles in diameter, which would fill the Earth's orbit, would appear no bigger than a dimenſionleſs point, if it were ſeen from any of the Stars: and the preſent ſubject will prove this to be true.

*E.* I am far from doubting the truth of your word; but I ſhould be very glad to ſee the demonſtration.

*N.* Then, here it is. Let the Earth be in what part of its orbit it will, we always find the interval of time (by the beſt clocks that are made) between any Star's revolving from the meridian to the meridian again, to be equal throughout the whole year: which it could not be, if the Earth's changing its place by a whole diameter of its orbit, bore any ſenſible proportion to the diſtance of the Stars. For then, if the hour and minute-hands of a clock ſhould revolve exactly 366 times from XII to XII again (there being ſuppoſed to be 24 hours on the dial plate) in the time of the Star's making 366 revolutions from the meridian to the meridian again; and the hands be ſet to the uppermoſt XII, when any given Star is on the meridian on the 21ſt of December; then, on the 20th of March afterward, when the hands were at the ſame XII as before, the ſame Star would be a little on the Eaſt ſide of the meridian, if the Earth's orbit were of any ſenſible bigneſs in proportion to the diſtance of the Star; and a little on the Weſt ſide of the meridian, when the hands were at XII on the 23d of September: but we never find any ſuch difference.

*E.* To me, your demonſtration is ſelf-evident.

*N.* Then, you are convinced, that when the meridian of any place has revolved from any Star to the ſame Star again, the Earth hath turned *abſolutely* once round its axis; becauſe the ſame meridian has revolved ſo, as to be again parallel to any fixed plane, to which it was parallel before, when the ſame Star was upon it.

*E.* I am.

*N.* Very well, ſiſter:——now, in *Fig.* 1. of PLATE V. let *S* be the Sun, *ABCDEFG* one half of the Earth's orbit; let the circle *h i k l k* be the Earth (at the top of the figure) and *a h* the meridian of London, which we ſhall ſuppoſe to be at *h*.

Let the ſtraight line *a h S* be produced onward, to five or ſix miles beyond the Sun, as ſeen from *h*; and let a Star be placed at the farthermoſt end of that line. ——Then, the diſtance of the Star from the Sun *S* will be ſo great, that the Earth's orbit *A B C*, &c. will bear no ſenſible proportion thereto, if it were viewed from the Star; and therefore, to an obſerver on the Earth at *h*, the Star will appear as even with the line *d h*, when the Earth has got a quarter round its orbit from *a* to *d*, and the meridian *d h* parallel to the poſition it had at *a h*, as when the Earth was at *a* in its orbit: So that, let the Earth be in what part of its orbit it will, the Star will always be upon the meridian of the place *h*, when *that* meridian has revolved to the ſame parallel poſition again: which it will always do in the time of the Earth's turning *abſolutely* round its axis.

*E.* Undoubtedly it will.

*N.* Now, ſuppoſe the Earth to advance in its orbit from *a* to *b*, in the time that it turns once round its axis; and then, the *ſame* meridian *b h* will be parallel to the poſition it had at *a h*, when the Sun and Star were *both* even with it; or, as we ſay, upon it.

Then it is plain, that when the Earth is at *b*, and the meridian *b h* has revolved from the Star to the Star again, it muſt revolve further on, from *b* to *m*, before it can go round from the Sun to the Sun again at *S*. And the arc, or part *h m*, of the Earth's circumference bears the ſame proportion to the Earth's whole circumference, that the arc, or part *a b*, of the circumference of the Earth's orbit bears to *its* whole circumference.

When the Earth is at *c* in its orbit, and the ſame meridian *c h* comes even with the Star the ſecond time, the meridian muſt revolve from *h* to *n* before it can be even with the Sun again, or the Sun be upon it the ſecond time.

When the Earth is at *d*, a quarter round its orbit from *a*, and the meridian *d h* is even with the Star; the meridian will want ſix hours of being even with the Sun in the right line *d o S*, and the place *h* muſt revolve 6 hours, or through the arc *h o* of 90 degrees, before the Sun can be on its meridian *d h*.

And conſequently, when the Earth has gone half round its orbit, the ſame meridian will be even with the Star twelve hours before it revolves to the Sun: and when the Earth has gone three quarters round its orbit, the meridian will be even with the Star 18 hours before it comes to be even with the Sun.

And laſtly, when the Earth has gone quite round its orbit, its rotation on its axis will have brought the ſame meridian once more round from the Star to the Star again, than from the Sun to the Sun again.——So that, let the year contain how many days it will, as meaſured by the apparent revolutions of the Sun from the meridian to the meridian again, it will contain one day more, as meaſured by the apparent revolutions of the Stars.

*E.* By this I find, that one abſolute turn of the Earth round its axis is loſt in a year with reſpect to the number of ſolar days in the year, becauſe the Earth's motion on its axis is the ſame way as its motion round the Sun. For, to bring any meridian round from the Sun to the Sun again, the Earth muſt turn as much more than quite round its axis, as bears a proportion to the ſpace it moves in its orbit in 24 ſolar hours. And therefore, to make the year contain 365 ſolar days and nights, the Earth muſt turn 366 times round its axis.

*N.* You are right, *Eudoſia.*—— Now go to your aſtronomical tables and precepts; and try whether you can calculate the time of new Moon in July 1748 old ſtile.——If you find any difficulty, come and tell me of it.

*E.* I thank you, brother; and make no doubt but that I muſt ſoon ſee you again.

* * *

# DIALOGUE X.

## *On the* PROJECTION *of* SOLAR ECLIPSES: *to which,* ANSWERS *to ſome* ASTRONOMICAL QUESTIONS *are ſubjoined.*

*Neander.*

WELL, ſiſter;——you kept quite alone, all the time yeſterday after you left me: and, as you did not return this morning before breakfaſt, as uſual, I ſent to enquire about your health: and the maid told me that you was very well; but ſo much engaged with your book and pen, that ſhe was almoſt afraid to ſpeak, for fear of diſturbing you; as you took no notice of her when ſhe came into your room.

*Eudoſia.* Indeed, brother, I have been very much engaged; and ſcarce took time to eat either dinner or ſupper.

*N.* So I obſerved; and now, pray, what have you been doing?

*E*. After looking a little at *Ferguſon*'s tables for calculating the true times of new and full Moons, and finding ſome expreſſions in the titles of the tables which I did not underſtand, namely, the *mean Anomalies* of the Sun and Moon; I read the former part of the 19th chapter of his book, in which I not only found *theſe terms* explained to my ſatisfaction; but alſo the *principles* on which the tables are conſtructed: and, on account of what you have already told me about the attractions of the Sun, Moon, and Earth, I think I underſtand the principles tolerably well.

*N.* I can very eaſily take your word for that, *Eudoſia*.

*E.* Having read the *precepts*, and compared them with the tables and *examples* of *calculation*, I then tried to calculate the true times of ſome new and full Moons which are exemplified in the precepts; and finding my calculations to agree very nearly with *Ferguſon*'s examples, I tried to calculate the true time of new Moon in July 1748, old ſtile, as you deſired me; of which Mr. *Ferguſon* has given no example.——And finding that the Sun muſt have been eclipſed at the time of *that* new Moon, I even *attempted* to take out the *elements* for projecting that eclipſe.

*N.* Then, indeed, you muſt have done a great deal of work for the time you have been about it.——Pray, ſhew me your calculations.

*E.* I am almoſt afraid to do it;——but, here they are.

| | day | h. | m. | s. |
|---|---|---|---|---|
| 1. The apparent time of new Moon at Greenwich, July in the Forenoon. | 14 | 11 | 15 | 3 |
| | | ° | ′ | ″ |
| 2. The ſemi-diameter of the Earth's diſc at that time, as ſeen from the Moon - | | 0 | 53 | 32 |
| 3. The angle of the Moon's viſible path with the ecliptic — — | | 5 | 35 | 0 |
| 4. The Moon's latitude, North deſcending | | 0 | 28 | 6 |
| 5. The Moon's horary motion from the Sun | | 0 | 27 | 17 |
| 6. The Sun's diſtance from the neareſt ſolſtice — — — | | 32 | 42 | 40 |
| 7. The Sun's declination, North — | | 19 | 35 | 21 |
| 8. The Sun's diſtance at noon from the vertex of London — — — | | 31 | 54 | 39 |
| 9. The Sun's ſemidiameter — — | | 0 | 15 | 50 |
| 10. The Moon's ſemidiameter — — | | 0 | 14 | 53 |
| 11. The ſemidiameter of the penumbra - | | 0 | 30 | 43 |

*N.* Well done, *Eudoſia.*—I calculated the ſame elements before I gave you the book; and now we will compare the calculations together.——All right;—for, do you ſee,—we have not differed three ſeconds in any part.——And I did not tell you till now, that I had made any ſuch calculation.

*E.* This gives me great pleaſure, indeed.——But, upon reading the method of projecting eclipſes, I often find mention made of a *Sector*; which I take to be a mathematical inſtrument; and, as you know that I am entirely unacquainted with any of theſe inſtruments, I am afraid I can proceed no further, unleſs you will ſhew me a Sector, and teach me how to uſe it.

*N.* It is true, that by means of a Sector, theſe kinds of projections may be much ſooner made than without it.——But, as I know you are yet totally unacquainted with mathematical inſtruments, I will now ſhew you how to project an eclipſe of the Sun, only by means of a pair of compaſſes and a common ruler: And then, you will be at no loſs about projecting any eclipſe of the Moon, which is much eaſier to be done than to project an eclipſe of the Sun.——I will firſt tell you ſome things, by which you will underſtand the reaſon why all the different parts of the conſtruction of a ſolar eclipſe muſt be as we lay them down; and then proceed to conſtruct the Sun's eclipſe which fell on the 14th of July, 1748, as it appeared at London. You know, it is but a few days ſince you covered one of the panes of glaſs in the window of your room with gum water; and, when it was dry, you placed yourſelf about a foot from the glaſs; and, keeping your head ſteady, you delineated a landſkip on the glaſs, with your black lead pencil, of all the diſtant objects which you ſaw through the glaſs, drawing them on thoſe parts of the glaſs which were juſt between them and your eye; as if the pencil had touched the objects themſelves.

*E.* I have often done ſo: then drawn them with ink (which the gum water cauſes to ſtick) and then laid a paper over them on the glaſs, and traced them thereon with the black lead pencil.

*N.* Now, ſuppoſe the Equator to be a viſible circle on the Earth, and that a circle is drawn through any place (as ſuppoſe London) parallel to the Equator: that the Earth had an axis put through it, projecting out a good way from its ſurface at each pole; and that there was a viſible line drawn perpendicular to the plane of the ecliptic or Earth's orbit, which line would be called the axis of the ecliptic.

Imagine all thoſe things would be viſible to an obſerver at the Sun; and ſuppoſe yourſelf to be there, holding a pane of glaſs between you and the Earth, and delineating the figure of the Earth thereon, with its axis, Equator, the circle parallel to the Equator paſſing through London, and the axis of the ecliptic, Then,

As the Earth turns round its axis from weſt to eaſt, the places on its ſurface would appear to you to move as from your left hand toward your right; and you would ſee London as moving over the Earth in the circle which is drawn through it, parallel to the Equator. And, when the Moon is new, and eclipſeth the Sun from any part of the Earth, you would ſee her between you and the Earth, as paſſing over it from left to right hand, the ſame way as it turns on its axis; and you would ſee a great part of the Moon's penumbra or partial ſhadow, all around her, (as it were) like a dark browniſh ring, travelling with her over the Earth.

As the Sun ſhines round the North pole of the Earth, from the 20th of March to the 23d of September, you would ſee *that* pole all the while in the enlightened part of the Earth's diſc (or flat round ſurface, as it would appear to you; like as the Sun and Moon do to us): and, from the 23d of September to the 20th of March, the ſame pole would be hid from your eye-ſight, behind the viſible and illuminated diſc of the Earth; becauſe it is in the dark all that time.

If a ſtraight walking-ſtick be placed at a diſtance from you, and inclining either directly toward you or from you, it will appear to you to be upright: but, if it inclines either toward your right or left hand, you will perceive it to do ſo. Therefore, when the Earth's axis inclines either directly toward you or from you at the Sun, it will appear to you to be perpendicular to the plane of the Earth's orbit or ecliptic; and to coincide with the axis of that plane. But, when the Earth's axis inclines more or leſs ſidewiſe to the Sun, the northern half of it will appear to you to incline from the axis of the ecliptic, toward your right or left hand; and the ſouthern half to incline the contrary way from the axis of the ecliptic: for then, theſe two axes will ſeem to croſs each other in the middle point of the Earth's axis.

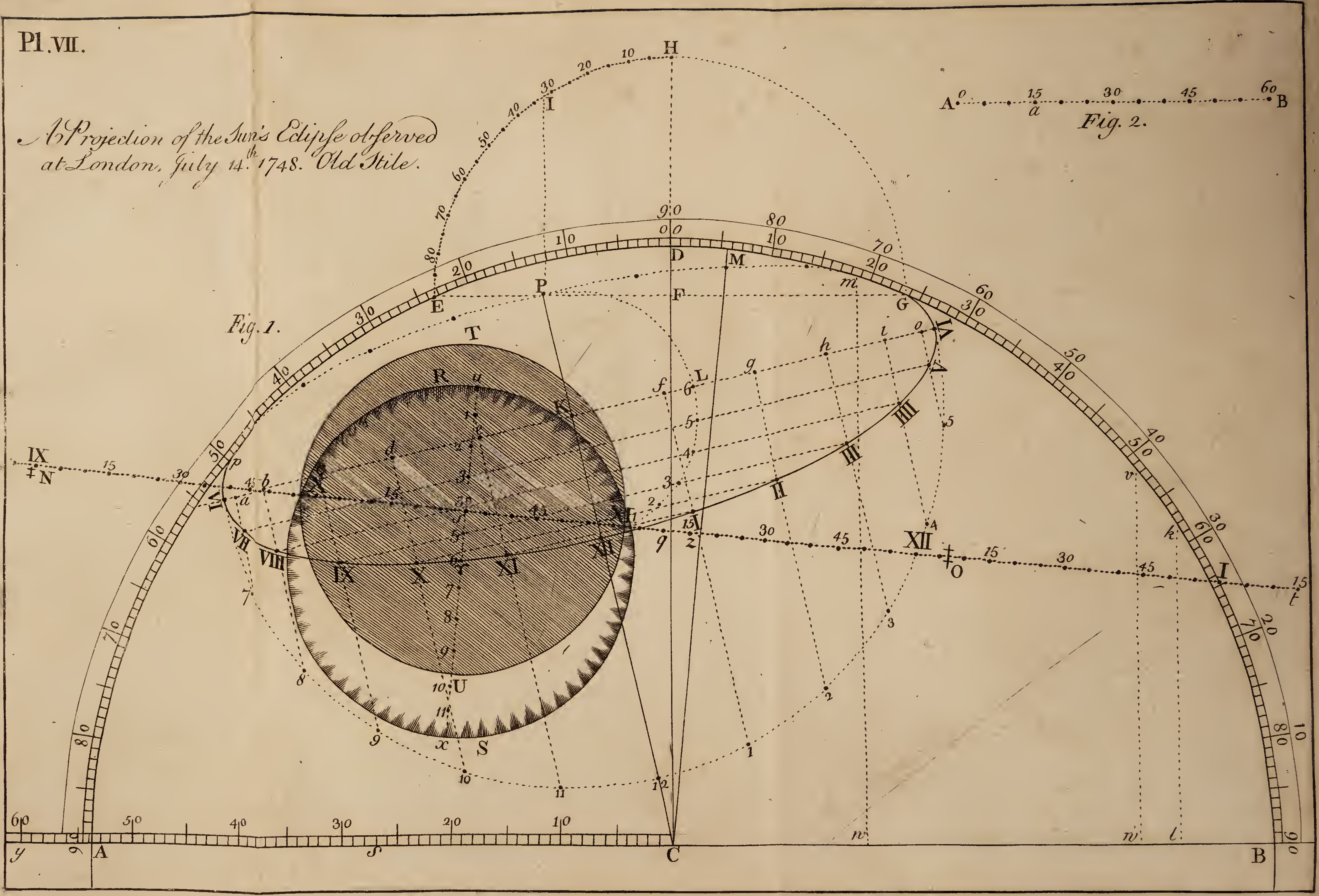
Now, as the Earth's axis really inclines 23½ degrees from a perpendicular to the plane of the Earth's orbit, and always keeps inclining to one and the ſame ſide of the Heavens, in the Earth's whole courſe round the Sun; it will appear in different poſitions of inclination to the axis of the ecliptic, as ſeen from the Sun, at different times of the year; the North pole being ſometimes toward your right hand from the axis of the ecliptic, and at other times toward your left hand from the axis of the ecliptic; conſtantly varying the apparent angle of its inclination, according to the time of the year.

From the 21ſt of December to the 21ſt of June, the North pole of the Earth's axis lies toward the right hand from the axis of the ecliptic, as ſeen from the Sun: and moſt of all ſo on the 20th of March. From the 21ſt of June to the 21ſt of December, the North pole of the Earth's axis lies more or leſs to the left hand, as ſeen from the Sun; and moſt of all ſo on the 23d of September.

*E.* I wiſh you would be ſo good as to write down theſe matters for me, when you are at leiſure; becauſe I am afraid I ſhall forget them.

*N.* You may depend upon it that I will; eſpecially as they are the very principles on which we are now about to conſtruct an eclipſe of the Sun: which is, in the firſt place, by delineating a figure of the Earth, with its axis, Equator, &c. according to their poſitions as ſuppoſed to be ſeen from the Sun (or from the Moon juſt between the Earth and the Sun) at the time of the eclipſe. Now, we will go to work, according to your calculated elements.

A Projection of the Sun's Eclipſe obſerved at London, July 14th 1748. Old Stile.



Make a ſcale, as *y A C* (PLATE VII. *Fig.* 1.) almoſt half the length of the paper intended for your projection, and divide it into 60 equal parts at leaſt, reckoning each part to be one minute, or a ſixtieth part of a degree.——Then, take the ſemidiameter of the Earth's diſc. 53 minutes 32 ſeconds (or 53½) from the ſcale, in your compaſſes; and with that extent, ſet one foot in the end *C* of the ſcale, as a center; and with the other foot deſcribe the ſemicircle *A B D*, for the circumference of the northern half of the Earth's illuminated diſc or ſurface, becauſe we live on the North ſide of the Equator: and continue the line *y A C* on to *B*; ſo, *A C B* ſhall be a portion of the Ecliptic equal to the diameter of the Earth as ſeen from the Moon at that time.

From the center *C*, raiſe the line *C D H*, perpendicular to *A C B*; and call the line *C D H* the axis of the ecliptic.

Divide the quadrants *A D* and *D B*, each into 90 equal parts for degrees, beginning at *D*. Then connect the points *E* and *G* (which are 23½ degrees on each ſide of *D*) with the ſtraight line *E F G*; in which line, the North pole *P* of the Earth's diſc will always be found.

Set one foot of the compaſſes in the point *F*, where the line *E F G* interſects the axis of the Ecliptic *CDH*; and, having extended the other foot from *F* to *E*, or from *F* to *G*, deſcribe the ſemicircle *E H G*, and divide its quadrant *H E* into 90 equal parts for degrees, becauſe the Earth's axis lies to the left hand from the axis of the Ecliptic, as ſeen from the Sun in the month July. ——If the Earth's axis had lain to the right hand from the axis of the Ecliptic, the quadrant *H G* muſt have been divided into 90 degrees, and not the quadrant *H E*.

As the Sun is 32 degrees 42 minutes 40 ſeconds (which may be eſtimated 32 degrees and four-ſixths, or two-thirds, of a degree) from the neareſt (or ſummer) ſolſtice, which is the firſt point of Cancer, on the noon of the 14th July 1748, draw the right line *I P*, parallel to *H D*, from $32\frac{2}{3}$ degrees of the quadrant *H E*, till it meets the line *E F G* at *P*: then, from *P* to *C*, draw the right line *P C*; ſo *P C* ſhall be the northern half of the Earth's axis, and *P* the North pole.

As the Sun is on the North ſide of the Equator in July, and conſequently nearer the point of the Heaven juſt over London (or the vertex of London) than the Equator is; ſubtract his declination, 19 degrees 35 minutes neglecting the 21 ſeconds) from the Latitude of London, 51 degrees 30 minutes, and the remainder will be 31 degrees 55 minutes for the Sun's diſtance from the vertex of London on the noon of July the 14th.

From the point *k* (in the right hand ſide of the ſemicircle *A D B*) at 31 degrees 55 minutes counted upward from *B*, draw the right line *k l*, parallel to *C D*: and taking the extent *k l* in your compaſſes, ſet it from *C* to XII on the Earth's axis *C P*. So, the point XII ſhall be the place of London on the Earth's diſc, as ſeen from the Sun, at the inſtant when it was noon at London on 14th of July 1748.

Add the Sun's declination, 19° 35′, to the Latitude of London 51° 30′, and the ſum will be 71 degrees 5 minutes, for the Sun's diſtance from the vertex of London on the 14th of July at midnight. Therefore,

From 71° 5′, counted upward in the right hand ſide of the ſemicircle *A D B* from *B* to *m*, draw the right line *m n* parallel to *C D*. Then, taking the extent *m n* in your compaſſes, ſet it from *C* towards or beyond *P* on the Earth's axis *C P*, as it happens to reach ſhort of *P* or beyond it: but in the preſent caſe, it reaches ſo little above *P*, that we may reckon *C P* to be its whole extent:

and ſo, the point *P* ſhall repreſent the place or ſituation of London at midnight, beyond the illuminated part of the Earth's diſc, as ſeen from the Sun; and conſequently in the dark part thereof.

Divide the part of the Earth's axis between XII and *P* into two equal parts, XII *K* and *P K*: then, through the point *K*, draw the right line VI *K* VI perpendicular to the Earth's axis *C* XII *K P*.

Subtract the Latitude of London, 51° 30′ from 90″ 00′; and there will remain $38\frac{1}{2}$ for its Co-latitude.——Then, from $38°\frac{1}{2}$, counted upward from *B* to *v* in the ſemicircle *A D B*, draw the right line *v w*; and, having taken its length in your compaſſes, ſet off that length both ways from *K* in the Earth's axis to VI and VI, in the line VI *K* VI.

Now, to draw the parallel of Latitude of London, or its path on the Earth's diſc, as ſeen from the Sun, from the time of Sun-riſe till the time of ſun-ſet at London; proceed as follows.

The compaſſes being opened from *K* to VI, ſet one foot in *K*, and with the other foot deſcribe the ſemicircle VI 7 8 9 10 11 12 1 2 3 4 5 VI, and divide it into twelve equal parts. Then, from the diviſion-points (7 8 9, &c.) draw the right lines 7*a*, 8*b*, 9*c*, 10*d*. &c. all parallel to the Earth's axis *C P*, as in the figure.

Set one foot of the compaſſes in *K*, and with the other foot deſcribe the ſemicircle *P L* XII, and divide its quadrant XII *L* into ſix equal parts, as at the points 1, 2, 3, 4, 5, 6; becauſe the Sun is on the North ſide of the Equator. If he had been on the South ſide of it, the quadrant *P L* (and not the quadrant XII *L*) muſt have been ſo divided.

Through the ſaid diviſion-points of the quadrant XII *L*, draw the right lines XI 1 I, X 2 II, IX 3 III, VIII 3 IV, and VII 5 V, all parallel to the right line VI *K* VI; and, through the points where theſe lines meet the former parallel lines 7*a*, 8*b*, 9*c*, 10*d*, &c. draw the elliptical curve VI VII VIII IX X XI XII I II III IV V VI; which may be done by hand, from point to point; and ſet the hour-letters to thoſe points where the right lines meet in the curve, as in the figure. This curve ſhall repreſent the parallel of Latitude of London, or the path which London (by the Earth's motion on its axis) appears to diſcribe on the Earth's diſc, as ſeen from the Sun on the 14th of July, from VI in the morning till VI at night: and the points VI, VII, VIII, IX, &c. in the curve ſhall be the points of the diſc where London would be at each of theſe hours reſpectively, as ſeen from the Sun. If the Sun's declination had been as far South as it was North, the dotted curve VI *P M* VI would have been the path of London; which muſt have been found by dividing the quadrant *P L*, into ſix equal parts, and drawing lines parallel to VI *K* VI between that line and the pole *P*, and continuing the lines 7*a*, 8*b*, 9*c*, &c. till they meet the foreſaid parallel lines drawn through the diviſion-points of the quadrant *P L.*——The points *p* and *G*, where the elliptical curve touch the circumference of the diſc, denote the inſtants of the Sun's riſing and ſetting at London: for, when London is at *p*, it will be juſt entering into the enlightened part of the Earth; and going into the dark, when it is at *G*.

From the point *M*, *viz.* 5 degrees 35 minutes to the right hand of the axis of the Ecliptic *C D*, draw the right line *M C* for the axis of the Moon's orbit, as ſeen from the Sun, becauſe the Moon's Latitude is *North deſcending*, on the 14th of July 1748.——If her Latitude had been *North Aſcending*, the axis of her orbit muſt have been drawn from *r* to *C*, on the left hand ſide from the axis of the Ecliptic.

Take the Moon's Latitude, 28′ 6′, from $C$ to $s$, with your compaſſes, in the ſcale $A\,C$, and ſet that extent from $C$ to $q$ on the axis $(C\,D)$ of the Ecliptic. ——Then, through the point $q$, draw the right line $N\,q\,O\,t$, perpendicular to the axis of the Moon's orbit $C\,z\,M$: and $N\,q\,O\,t$ ſhall be the path of the center of the Moon's ſhadow over the Earth; and will repreſent as much of the Moon's orbit, ſeen from the Sun, as ſhe moves through, during the time that her ſhadow or penumbra is going over the Earth.

From $C$, on the ſcale $A\,C$, take the Moon's horary motion from the Sun, 27′ 17″, in your compaſſes; and make the line $A\,B$ (*Fig.* 2.) equal in length to *that* extent: and divide the ſaid line into 60 equal parts, for ſo many minutes of time.——Then, as the time of new Moon, on the 14th of July 1748, was at 15 minutes 3 ſeconds after XI o'clock, take 15 minutes (neglecting the three ſeconds) from $A$ to $a$ on the line $A\,B$ in your compaſſes, and ſet them off, in *Fig.* 1. from the *middle point* between $q$ and $z$, in the right line $N\,q\,z\,O$, to XI in that line; becauſe the tabular time of new Moon is mid-way between the point $q$, where the axis $C\,D$ of the Ecliptic and the axis $C\,M$ of the Moon's orbit cuts the line or path of the penumbra's center on the Earth.

Take the whole length of the line $A\,B$ (*Fig.* 2.) in your compaſſes; and, with that extent, make marks along the line $N\,O$ (*Fig.* 1.) both ways from XI; and ſet the hour-letters to theſe marks, as in the figure. —Then, divide each ſpace, from mark to mark, into ſixty equal parts or horary minutes, which ſhall ſhew the points of the Earth's diſc where the center of the penumbra falls, at every hour and minute, during its tranſit over the Earth.

Apply one ſide of the ſquare to the line of the penumbra's path $N\,O$, and move the ſquare forward or backward till the other ſide cuts the ſame hour and minute, as at *s* and *r*, both in the path of the penumbra's center and the path of London: and the *minute*, which the ſquare cuts at the ſame inſtant in both theſe paths, is the *inſtant* of the viſible conjunction of the Sun and Moon at London; and conſequently, of the greateſt obſcuration of the Sun by the Moon; which, according to the projection, is at 30 minutes paſt X o'clock in the morning.

Take the Sun's ſemidiameter, 15′ 50″, in your compaſſes from the ſcale; and ſetting one foot at *r* as a center, in the path of London; with the other foot deſcribe the circle *R S* for the Sun, as ſeen from London at the time of the greateſt obſcuration. Then, take the Moon's ſemidiameter, 14′ 53″, in your compaſſes from the ſcale; and ſetting one foot in the Moon's path at *s*, with the other foot deſcribe the circle *T U* for the Moon, as ſeen from London, when ſhe obſcures moſt of all of the Sun, during the eclipſe; which may be meaſured by a diameter line *u s r x*, drawn acroſs the Sun through the points *s* and *r*, and divided into 12 equal parts for digits of the Sun's diameter: of which, according to the preſent projection, there are $9\frac{2}{3}$ digits eclipſed.

Take the ſemidiameter of the penumbra, 30′, 43″, from the ſcale in your compaſſes; and, ſetting one foot in the path of the penumbra's center, direct the other foot to the path of London among the morning hours at the left hand; and carry that extent backwards and forwards, till both the points of the compaſſes fall into the ſame inſtant at both the paths; which inſtant will denote the time when the eclipſe began at London. Then, do the like among the afternoon hours; and where the point of the compaſſes fall into the ſame inſtants in both the paths, they will ſhew at what time the eclipſe ended at London.——Theſe trials ſhew that the beginning of the eclipſe was juſt at IX o'clock in the morning, and its ending at 7 minutes after XII o'clock at noon; as the compaſſes reach juſt from IX in the path of London to IX in the path of the penumbra's center; and from 7 minutes after XII in the path of London, to 7 minutes after XII in the path of the penumbra's center. —— Thus, we have, at laſt, finiſhed the projection, and found what was wanted to be known from it.

*E.* The whole proceſs is very pleaſant, but, I think, it is ſomewhat tedious.

*N.* That is, becauſe we have been obliged to divide the ſemicircle *A D B* and the quadrant *E H* with a pair of compaſſes.——If the Sector had been uſed, the labour would have been much ſhortened, becauſe we could have taken off all the meaſures directly from it; and ſo, have avoided all the trouble of dividing, not only of the ſemicircle and quadrant, but alſo even of the ſcale.

*E.* I wiſh you would teach me how to uſe the Sector.

*N.* I will ſend to my mathematical inſtrument-maker, Mr. *Bennet*, in Crown Court, near St. Ann's Church, Soho, for a compleat caſe of mathematical inſtruments, and will make you a preſent of it, and inſtruct you how to uſe them before I leave this place, In the mean time, I will aſk you a few queſtions relative to the ſubjects we have been upon: and, if you can anſwer them cleverly, I ſhall not ſcruple to tell you, that you have made a very extraordinary progreſs.

*E.* I thank you, Sir, for your intended preſent and future inſtructions: and will anſwer your queſtions as well as I can *.

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* The ſubject of what is here put down, by way of queſtion and anſwer, was given by the author ſome time ago to a gentleman who has ſince publiſhed it, not without the author's leave, at the end of a printed book.

*N*. What would be the conſequence, if the Earth were fixed in any point of its orbit, ſo as to have no progreſſive motion therein; and to turn round its axis with its preſent velocity, having its axis perpendicular to the plane of the Ecliptic?

*E*. The ſolar, or natural day would be of the ſame length with the ſydereal day; which is equal to 23 hours 56 minutes 4 ſeconds of the time now meaſured by a well regulated clock. The Sun would conſtantly appear to revolve in the Equator, days and nights would always be of an equal length at all places, either near the poles or far from them. And conſequently, there would be no different ſeaſons.

*N*. What would be the conſequence, if the Moon's diſtance from the Earth was ſuch, as that ſhe ſhould appear to be of the ſame magnitude with the Sun; that her orbit were circular, and lay in the plane of the Ecliptic; and that ſhe moved round the Earth in her orbit with her preſent velocity?

*E*. The Moon would always revolve in the plane of the Equator; and (ſuppoſing the Earth had no progreſſive motion in its orbit) the Moon would go round from change to change in the time ſhe now goes round her orbit, which is, in 27 days 7 hours 43 minutes 5 ſeconds. The diameters of the Sun and Moon would always appear to be equal. The Moon would eclipſe the Sun totally, for an inſtant of time, at all thoſe places over which the center of her ſhadow paſſed, which would be directly along the Equator. The eclipſes would be only partial on different ſides of the Equator, and never viſible at more than 2350 miles from it. The Moon would be totally eclipſed in the Earth's ſhadow at every time ſhe was full; and the durations of all her eclipſes would be equal.

*N.* What would be the conſequence, if the Moon's orbit acquired an elliptical form, ſuch as it is now of: that it continued in the plane of the Ecliptic, and the Earth had no progreſſive motion, but only turned round its axis as before?

*E.* The lengths of days and nights would be the ſame as above, and the times between the new or full Moons would remain the ſame. The Sun would be eclipſed (as above) at every change, and the Moon at every full; and the center of the Moon's ſhadow, when the Moon is new, would always paſs along the Equator. If the changes fell in that part of the Moon's orbit which is furtheſt from the Earth, the Sun would never be totally eclipſed; but would appear like a fine luminous ring all around the dark body of the Moon, at theſe places on the Equator where the Moon were directly over head at the inſtant of the change. If the changes fell in that part of the Moon's orbit which is neareſt the Earth, all the eclipſes of the Sun would be total at the Equator, for about four minutes of time: But if they fell in either of the two parts of the Moon's orbit which are at a mean between thoſe parts which are at the greateſt and leaſt diſtance from the Earth, the eclipſes of the Sun would be juſt total for an inſtant of time at the Equator, and no where elſe. All the Moon's eclipſes would be total with continuance, as above.

*N.* Suppoſe now, that the Earth ſhould revolve about the Sun, with its preſent velocity, in the plane of the Ecliptic, its axis keeping always perpendicular thereto: that the Moon ſhould revolve as above, with her preſent velocity; and that her orbit ſhould remain always in the plane of the Ecliptic?

*E.* In that caſe, the days and nights would always continue (as above) of equal length; only the 24 ſolar hours would be 3 minutes 56 ſeconds longer than the

24 ſydereal hours, as they now are; but there would be no different ſeaſons. The Moon would go round her orbit in 27 days 7 hours 43 minutes 5 ſeconds; and round from the Sun to the Sun again, or from change to change, in 29 days 12 hours 44 minutes 3 ſeconds; as ſhe now does. The Sun would be eclipſed (as above) at every change, and the Moon at every full; and all the Sun's eclipſes would be central only at the Equator; but they would ſometimes be total there for four minutes, ſometimes total only for an inſtant, and at other times annular; according to the diſtance of the Moon from the Earth in different parts of her elliptical orbit at theſe times.

*N.* With the above circumſtances, relating to the Earth's progeſſive motion in its orbit, and the Moon's motion in her orbit; what would be the conſequence if the Earth's axis ſhould become inclined to the Ecliptic, as it now is; and the earth turn round its axis with its preſent velocity?

*E.* We ſhould then have all the variety of ſeaſons we now enjoy. The times between the new and full Moons would be the ſame as in the laſt anſwer above, and the eclipſes of the Sun and Moon the ſame. Only, the Sun's central eclipſes would not fall always at the Equator, but ſometimes on one ſide of it, and ſometimes on the other; that is, between the Equator and *that* pole of the Earth which was inclining toward the Sun at the time of the eclipſe.——In our Spring, the center of the Moon's ſhadow would go obliquely over the Earth, from the ſouthern tropic to the northern.—In ſummer, the ſhadow would begin to take the Earth at the Equator, and thence bend its courſe to the northern tropic, and from that tropic to the Equator again, where it would leave the Earth. In our autumn, the center of the Moon's ſhadow would go obliquely over the Earth, from the northern tropic to the ſouthern : —— and, in winter, it would take the Earth at the Equator, from which it would bend its courſe to the ſouthern tropic, and go on obliquely from that tropic to the Equator, where it would leave the Earth. And, in each of theſe four caſes, the Sun's eclipſe would be central to all the parts of the Earth over which the center of the Moon's ſhadow paſſed ; ſometimes total only for an inſtant, ſometimes total for four minutes, and at other times only annular.——The eclipſes of the Moon would be as above.

*N.* Suppoſing now, that the Moon's orbit ſhould become inclined to the Ecliptic, as it is at preſent, but that her nodes ſhould have no motion therein ; and every other circumſtance ſhould remain as in the laſt queſtion ?

*E.* Then, the Sun would never be eclipſed at more than 17 degrees from either of the nodes, at the time of any new Moon whatever ; nor would the Moon be eclipſed at more than 12 degrees from either of the nodes at any time whatever of being full. So that we ſhould have but few eclipſes (as is now the caſe) in compariſon of the number of our new and full Moons. And the eclipſes would be confined to the ſame ſeaſons of the year ; for there would be half a year between thoſe which happened about one node and about the other, becauſe there would be juſt half a year between the conjunctions of the Sun with one node and with the other.

*N.* Every thing remaining as above, excepting the ſtability of the nodes, and of thoſe two points of the Moon's orbit which are moſt and leaſt diſtant from the Earth : What would be the conſequence if theſe points acquired a direct or forward motion in the Moon's orbit, and her nodes a backward or retrograde motion ; as they now have ?

*E.* I believe, every circumſtance would be as it now is: and therefore, we ſhould have all the variety of eclipſes that now exiſts in nature.

*N.* Well done, *Eudoſia!*——You have anſwered all my queſtions to my mind: which you could not poſſibly have done, unleſs you had very well remembered the ſubjects we have been upon, in all our Ten Dialogues. This, I think, may be our laſt on Aſtronomy; becauſe your applying to books will ſuperſede all neceſſity of our having any more.

*E.* But I am extremely ſorry, brother, to have heard yeſterday, that you are to ſet out for Italy in a few days, which is much ſooner than was expected. I ſhall miſs you ſadly;——and as you will probably be gone before I can read *Ferguſon*'s Aſtronomy quite through; I ſhould be glad to know whether you would have me to read any other book upon the like ſubject afterward.

*N.* By all means.——Here is Doctor *Long*'s Aſtronomy:—take it and keep it; for it will afford you a great deal of entertaining and pleaſing knowledge, eſpecially in the hiſtorical part.——You may ſkip over thoſe parts which are geometrical, as I ſhall not now have time to inſtruct you in that branch of ſcience. 'Tis true, the volume is large; but I will anſwer for it, that by the time you have got to the end, you will wiſh it had been much larger, and that the Doctor would finiſh his ſecond volume.

*E.* Permit me, dear brother, to thank you moſt ſincerely for this valuable preſent.

FINIS.

THE

# DESCRIPTION

AND USE OF THE

# GLOBES,

AND

## ARMILLARY SPHERE.

# THE DESCRIPTION AND USE OF THE GLOBES, &c.

## *The deſcription and uſe of the globes, and armillary ſphere.*

The *terreſtrial globe.*

IF a map of the world be accurately delineated on a ſpherical ball, the ſurface thereof will repreſent the ſurface of the earth: for the higheſt hills are ſo inconſiderable with reſpect to the bulk of the earth, that they take off no more from its roundneſs, than grains of ſand do from the roundneſs of a common globe; for the diameter of the earth is 8000 miles, in round numbers, and no known hill upon it is three miles in perpendicular height.

That

Proof of the earth's being globular.

That the earth is ſpherical, or round like a globe, appears, 1. from its caſting a round ſhadow upon the moon, whatever ſide be turned towards her when ſhe is eclipſed. 2. From its having been ſailed round by ſeveral perſons. 3. From our ſeeing the farther, the higher we ſtand. 4. From our ſeeing the maſts of a ſhip, whilſt the hull is hid by the convexity of the water.

And that it may be peopled on all ſides without any one's being in danger of falling away from it.

The attractive power of the earth draws all terreſtrial bodies towards its center; as is evident from the deſcent of bodies in lines perpendicular to the earth's ſurface, at the places whereon they fall; even when they are thrown off from the earth on oppoſite ſides, and conſequently, in oppoſite directions. So that the earth may be compared to a great magnet rolled in filings of ſteel, which attracts and keeps them equally faſt to its ſurface on all ſides. Hence, as all terreſtrial bodies are attracted toward the earth's center, they can be in no danger of falling from any ſide of the earth, more than from any other.

*Up* and *down*, what.

The heaven or ſky ſurrounds the whole earth; and when we ſpeak of *up* or *down*, we mean only with regard to ourſelves; for no point, either in the heaven, or on the ſurface of the earth, is *above* or *below*, but only with reſpect to ourſelves. And let us be upon what part of the earth we will, we ſtand with our feet toward its center, and our heads toward the ſky: and ſo we ſay, it is *up* toward the ſky, and *down* toward the center of the earth.

All objects in the heaven appear equally diſtant.

To an obſerver placed any where in the indefinite ſpace, where there is nothing to limit his view, all remote objects appear equally diſtant from him; and ſeem to be placed in a vaſt concave ſphere, of which his eye is the center. Every aſtronomer can demonſtrate, that the moon is much nearer to us than the ſun is; that ſome of the planets are ſometimes nearer to us, and ſometimes farther from us, than the ſun; that others of them never come ſo near us as the ſun always is; that the remoteſt planet in our ſyſtem, is beyond compariſon nearer to us than any of the fixed ſtars are; and that it is highly probable ſome ſtars are, in a manner, infinitely more diſtant from us than others. And yet all theſe celeſtial objects appear equally diſtant from us. Therefore, if we imagine a large hollow ſphere of glaſs to have as many bright ſtuds fixed to its inſide, as there are ſtars viſible in the heaven, and theſe ſtuds to be of different magnitudes, and placed at the ſame angular diſtances from each other as the ſtars are; the ſphere will be a true repreſentation of the ſtarry heaven, to an eye ſuppoſed to be in its center, and viewing it all around. And if a ſmall globe, with a map of the earth upon it, be placed on an axis in the center of this ſtarry

The face of the heaven and earth repreſented in a machine.

ſphere, and the ſphere be made to turn round on this axis, it will repreſent the apparent motion of the heavens round the earth.

If a great circle be ſo drawn upon this ſphere, as to divide it into two equal parts, or hemiſpheres, and the plane of the circle be perpendicular to the axis of the ſphere, this circle will

The *equinoctial.*

repreſent the *equinoctial*, which divides the heaven into two equal parts, called the *northern* and the *ſouthern hemiſpheres*; and every point of that circle will be equally diſtant from the *poles*, or

The *poles.*

ends of the axis in the ſphere. That pole which is in the middle of the northern hemiſphere, will be called the *north pole of the ſphere*, and that which is in the middle of the ſouthern hemiſphere, the *ſouth pole.*

If another great circle be drawn upon the ſphere, in ſuch a manner as to cut the equinoctial at an angle of 23½ degrees in two oppoſite

The *ecliptic.*

points, it will repreſent the *ecliptic*, or circle of the ſun's apparent annual motion: one half of which is on the north ſide of the equinoctial, and the other half on the ſouth.

If a large ſtud be made to move eaſtward in this ecliptic, in ſuch a manner as to go quite round it, in the time that the ſphere is turned round weſtward 366 times upon its axis; this

The *ſun.*

ſtud will repreſent the *ſun*, changing his place every day a 365th part of the ecliptic; and going round weſtward, the ſame way as the ſtars do; but with a motion ſo much ſlower than the motion of the ſtars, that they will make 366 revolutions about the axis of the ſphere, in the time that the ſun makes only 365. During one half of theſe revolutions, the ſun will be on the north ſide of the equinoctial; during the other half, on the ſouth; and at the end of each half, in the equinoctial.

The *earth.*

If we ſuppoſe the terreſtrial globe in this machine to be about one inch in diameter, and the diameter of the ſtarry ſphere to be about five or ſix feet, a ſmall inſect on the globe would ſee only a very little portion of its ſurface; but it would ſee one half of the ſtarry ſphere; the convexity of the globe hiding the other half from its view. If the ſphere be turned weſtward round the globe, and the inſect could judge of the appearances which ariſe from that motion, it would ſee ſome ſtars riſing to its view on the eaſtern ſide of the ſphere, whilſt others were ſetting on the weſtern: but as all the ſtars are fixed to the ſphere, the ſame ſtars would always riſe in the ſame points of view on the eaſt ſide, and ſet in the ſame points of view on the weſt-ſide. With the ſun it would be otherwiſe, becauſe the ſun is not fixed to any point of the ſphere, but moves ſlowly along an oblique circle in it. And if the inſect ſhould look towards the ſouth, and call that point of the globe, where the equinoctial in the ſphere ſeems

The apparent motion of the heavens.

ſeems to cut it on the left ſide, the *eaſt point*; and where it cuts the globe on the right ſide, the *weſt point*; the little animal would ſee the ſun riſe north of the eaſt, and ſet north of the weſt, for 182½ revolutions; after which, for as many more, the ſun would riſe ſouth of the eaſt, and ſet ſouth of the weſt. And in the whole 365 revolutions, the ſun would riſe only twice in the eaſt point, and ſet twice in the weſt. All theſe appearances would be the ſame, if the ſtarry ſphere ſtood ſtill (the ſun only moving in the ecliptic) and the earthly globe were turned round the axis of the ſphere eaſtward. For, as the inſect would be carried round with the globe, he would be quite inſenſible of its motion; and the ſun and ſtars would appear to move weſtward.

*We* are but very ſmall beings when compared with our earthly globe, and *the globe itſelf* is but a dimenſionleſs point compared with the magnitude of the ſtarry heavens. Whether the earth be at reſt, and the heaven turns round it, or the heaven be at reſt, and the earth turns round, the appearance to us will be exactly the ſame. And becauſe the heaven is ſo immenſely large, in compariſon of the earth, we ſee one half of the heaven as well from the earth's ſurface, as we could do from its center, if the limits of our view are not intercepted by hills.

*Circles of the ſphere.*

We may imagine as many circles deſcribed upon the earth as we pleaſe; and we may imagine the plane of any circle deſcribed upon the earth to be continued, until it marks a circle in the concave ſphere of the heavens.

*The horizon.*

The *horizon* is either *ſenſible* or *rational.* The *ſenſible* horizon is that circle, which a man ſtanding upon a large plane, obſerves to terminate his view all around, where the heaven and earth ſeem to meet. The plane of our ſenſible horizon continued to the heaven, divides it into two hemiſpheres; one viſible to us, the other hid by the convexity of the earth.

The plane of the *rational horizon,* is ſuppoſed parallel to the plane of the ſenſible; to paſs through the center of the earth, and to be continued to the heavens. And although the plane of the ſenſible horizon touches the earth in the place of the obſerver, yet *this* plane, and *that* of the rational horizon, will ſeem to coincide in the heaven, becauſe the whole earth is but a point compared to the ſphere of the heaven.

The earth being a ſpherical body, the horizon, or limit of our view, muſt change as we change our place.

*Poles.*

The *poles of the earth,* are thoſe two points on its ſurface in which its axis terminates. The one is called the *north pole*, and the other the *ſouth pole.*

The *poles of the heaven*, are thoſe two points in which the earth's axis produced terminates in the heaven: ſo that the *north pole* of the heaven is directly over the north pole of the earth; and the *ſouth pole* of the heaven is directly over the ſouth pole of the earth.

*Equator.* The *equator* is a great circle upon the earth, every part of which is equally diſtant from either of the poles. It divides the earth into two equal parts, called the *northern* and *ſouthern hemiſpheres.* If we ſuppoſe the plane of this circle to be extended to the heaven, it will mark the *equinoctial* therein, and will divide the heaven into two equal parts, called the *northern* and *ſouthern* hemiſpheres of the heaven.

*Meridian.* The *meridian* of any place is a great circle paſſing through that place and the poles of the earth. We may imagine as many ſuch meridians as we pleaſe, becauſe any place that is ever ſo little to the eaſt or weſt of any other place, has a different meridian from that place; for no one circle can paſs through any two ſuch places and the poles of the earth.

The *meridian* of any place is divided by the poles, into two ſemicircles: that which paſſes through the place is called the *geographical*, or *upper meridian*; and that which paſſes through the oppoſite place, is called the *lower meridian.*

*Noon* and *midnight.*

When the rotation of the earth brings the plane of the geographical meridian to the ſun, it is *noon* or *mid-day* to that place; and when the lower meridian comes to the ſun, it is *midnight.*

All places lying under the ſame geographical meridian, have their noon at the ſame time, and conſequently all the other hours. All thoſe places are ſaid to have the ſame *longitude,* becauſe no one of them lies either eaſtward or weſtward from any of the reſt.

*Hour-circles.*

If we imagine 24 ſemicircles, one of which is the geographical meridian of a given place, to meet at the poles, and to divide the equator into 24 equal parts; each of theſe meridians will come round to the ſun in 24 hours, by the ſun's equable motion round its axis in that time. And, as the equator contains 360 degrees, there will be 15 degrees contained between any two of theſe meridians which are neareſt to one another: for 24 times 15 is 360. And as the earth's motion is eaſtward, the ſun's apparent motion will be weſtward, at the rate of 15 degrees each hour, Therefore, *Longitude.* They whoſe geographical meridian is 15 degrees eaſtward from us, have noon, and every other hour, an hour ſooner than we have. They whoſe meridian is fifteen degrees weſtward from us, have noon, and every other hour, an hour later than we have: and ſo on in proportion, reckoning one hour for every fifteen degrees.

As the earth turns round its axis once in 24 hours, and ſhews itſelf all round to the ſun in that time; ſo it goes round the ſun once a year, *Ecliptic.* in a great circle called the *ecliptic*, which croſſes the equinoctial in two oppoſite points, making an angle of 23½ degrees with the equinoctial on each ſide. So that one half of the ecliptic is in the northern hemiſphere, and the other in the ſouthern. It contains 360 equal parts, called degrees (as all other circles do, whether great or ſmall) and as the earth goes once round it every year, the ſun will appear to do the ſame, changing his place almoſt a degree, at a mean rate, every 24 hours. So that whatever place, or degree of the ecliptic, the earth is in at any time, the ſun will then appear in the oppoſite. And as one half of the ecliptic is on the north ſide of the equinoctial, and the other half on the ſouth; the ſun, as ſeen from the earth, will be half a year on the ſouth ſide of the equinoctial, and half a year on the north: and twice a year in the equinoctial itſelf.

The

*Signs and degrees.*

The ecliptic is divided by aſtronomers into 12 equal parts, called *ſigns*, each ſign into 30 *degrees*, and each degree into 60 *minutes* : but in uſing the globes, we ſeldom want the ſun's place nearer than half a degree of the truth.

The names and characters of the 12 ſigns are as follow ; beginning at that point of the ecliptic where it croſſes the equinoctial to the northward, and reckoning eaſtward round to the ſame point again. And the days of the months on which the ſun now enters the ſigns, are ſet down below them.

| | | | |
|---|---|---|---|
| *Aries,* | *Taurus,* | *Gemini,* | *Cancer,* |
| ♈ | ♉ | ♊ | ♋ |
| March | April | May | June |
| 20 | 20 | 21 | 21 |
| *Leo,* | *Virgo,* | *Libra,* | *Scorpio* |
| ♌ | ♍ | ♎ | ♏ |
| July | Auguſt | September | October |
| 23 | 23 | 23 | 23 |
| *Sagittarius,* | *Capricorn,* | *Aquarius,* | *Piſces,* |
| ♐ | ♑ | ♒ | ♓ |
| November | December | January | February |
| 22 | 21 | 20 | 18 |

By remembering on what day the ſun enters any particular ſign, we may eaſily find his place any day afterward, whilſt he is in that ſign, by reckoning a degree for each day; which will occaſion no error of conſequence in uſing the globes.

When the ſun is at the beginning of *Aries*, he is in the equinoctial; and from that time he declines northward every day, until he comes to the beginning of *Cancer*, which is 23½ degrees from the equinoctial: from thence he recedes ſouthward every day, for half a year; in the middle of which half, he croſſes the equinoctial at the beginning of *Libra*, and at the end of that half year, he is at his greateſt ſouth declination, in the beginning of *Capricorn*, which is alſo 23½ degrees from the equinoctial. Then, he returns northward from *Capricorn* every day, for half a year; in the middle of which half, he croſſes the equinoctial at the beginning of *Aries*; and at the end of it he arrives at *Cancer*.

The ſun's motion in the ecliptic is not perfectly equable, for he continues eight days longer in the northern half of the ecliptic, than in the ſouthern: ſo that the ſummer half year, in the northern hemiſphere, is eight days longer than the winter half year; and the contrary in the ſouthern hemiſphere.

*Tropics.* The *tropics* are leſſer circles in the heaven, parallel to the equinoctial; one on each ſide of it, touching the ecliptic in the points of its greateſt declination; ſo that each tropic is 23½ degrees from the equinoctial, one on the north ſide of it, and the other on the ſouth. The northern tropic touches the ecliptic at the beginning of *Cancer*, the ſouthern at the beginning of *Capricorn*; for which reaſon the former is called the *tropic of Cancer*, and the latter the *tropic of Capricorn*.

The *polar circles* in the heaven, are each 23½ degrees from the poles, all around. That which goes round the north pole, is called the *arctic circle*, from ἄρκτος, which ſignifies a *bear*; there being a conſtellation or groupe of ſtars near the north pole, which goes by that name. The ſouth polar circle, is called the *antarctic circle*, from its being oppoſite to the arctic. *Polar-circles.*

The ecliptic, tropics, and polar circles, are drawn upon the terreſtrial globe, as well as upon the celeſtial. But the ecliptic, being a great fixed circle in the heavens, cannot properly be ſaid to belong to the terreſtrial globe; and is laid down upon it only for the conveniency of ſolving ſome problems. So that, if this circle on the terreſtrial globe was properly divided into the months and days of the year, it would not only ſuit the globe better, but would alſo make the problems thereon much eaſier.

In order to form a true idea of the earth's motion round its axis every 24 hours, which is the cauſe of day and night; and of its motion in the ecliptic round the ſun every year, which is the cauſe of the different lengths of days and nights, and of the viciſſitude of ſeaſons; take the following method, which will be both eaſy and pleaſant.

An idea of the ſeaſons.

Let a ſmall terreſtrial globe, of about three inches diameter, be ſuſpended by a long thread of twiſted ſilk, fixt to its north pole: then, having placed a lighted candle on a table, to repreſent the ſun, in the center of a hoop of a large caſk, which may repreſent the ecliptic, the hoop making an angle of 23½ degrees with the plane of the table; hang the globe within the hoop near to it; and if the table be level, the equator of the globe will be parallel to the table, and the plane of the hoop will cut the equator at an angle of 23½ degrees; ſo that one half of the equator will be above the hoop, and the other half below it: and the candle will enlighten one half of the globe, as the ſun enlightens one half of the earth, whilſt the other half is in the dark.

Things being thus prepared, twiſt the thread towards the left hand, that it may turn the globe the ſame way by untwiſting; that is, from weſt, by ſouth, to eaſt. As the globe turns round its axis or thread, the different places of its ſurface will go regularly through the light and dark; and have, as it were, an alternate return of day and night in each rotation. As the globe continues to turn round, and to ſhew itſelf all around to the candle, carry it ſlowly round the hoop by the thread, from weſt, by ſouth, to eaſt; which is the way that the earth moves round the ſun, once a year, in the ecliptic: and you will ſee, that whilſt the globe continues in the lower part of the hoop, the candle (being then north of the equator) will conſtantly ſhine round the north pole; and all the northern places which go through any part of the dark, will go through a leſs portion of it than they do of the light; and the more ſo, the farther they are from the equator: conſequently, their days are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the higheſt and loweſt points, the candle will be directly over the equator, and will enlighten the globe juſt from pole to pole; and then, every place on the globe will go through equal portions of light and darkneſs, as it turns round its axis; and conſequently, the day and night will be of equal length at all places upon it. As the globe advances thenceforward, towards the higheſt part of the hoop, the candle will be on the ſouth ſide of the equator, ſhining farther and farther round the ſouth pole, as the globe riſes higher and higher in the hoop; leaving the north pole as much in darkneſs, as the ſouth pole is then in the light, and making long days and ſhort nights on the ſouth ſide of the equator, and the contrary on the north ſide, whilſt the globe continues in the northern or higher ſide of the hoop: and when it comes to the higheſt point, the days will be at the longeſt, and the nights at the ſhorteſt, in the ſouthern hemiſphere; and the reverſe in the northern. As the globe advances and deſcends in the hoop, the light will gradually recede from the ſouth pole, and approach towards the north pole, which will cauſe the northern days to lengthen, and the ſouthern days to ſhorten in the ſame proportion. When the globe comes to the middle point, between the higheſt and loweſt points of the hoop, the candle will be over the equator, enlightening the globe juſt from pole to pole, when every place of the earth (except the poles) will go through equal portions of light and darkneſs; and conſequently, the day and night will be then equal, all over the globe.

And thus at a very ſmall expence, one may have a delightful and demonſtrative view of the cauſe of days and nights, with their gradual increaſe and decreaſe in length, through the whole year together, with the viſſitudes of ſpring, ſummer, autumn, and winter, in each annual courſe of the earth round the ſun.

If the hoop be divided into 12 equal parts, and the ſigns be marked in order upon it, beginning with *Cancer* at the higheſt point of the hoop, and reckoning eaſtward (or contrary to the apparent motion of the ſun) you will ſee how the ſun appears to change his place every day in the ecliptic, as the globe advances eaſtward along the hoop, and turns round its own axis: and that when the earth is in a low ſign, as at *Capricorn*, the ſun muſt appear in a high ſign, as at *Cancer*, oppoſite to the earth's real place: and that whilſt the earth is in the ſouthern half of the ecliptic, the ſun appears in the northern half, and *vice verſa*: that the farther any place is from the equator, between it and the polar circle, the greater is the difference between the longeſt and ſhorteſt day at that place, and that the poles have but one day and one night in the whole year.

Theſe things premiſed, we ſhall proceed to the deſcription and uſe of the terreſtrial globe, and explain the geographical terms as they occur in the problems.

The *terreſtrial globe* deſcribed.

This globe has the boundaries of land and water laid down upon it, the countries and kingdoms divided by dots, and coloured to diſtinguiſh them, the iſlands properly ſituated, the rivers and principal towns inſerted, as they have been aſcertained upon the earth by meaſurement and obſervation.

The equator, ecliptic, tropics, polar circles, and meridians, are laid down upon the globe in the manner already deſcribed. The ecliptic is divided into 12 ſigns, and each ſign into 30

degrees,

degrees, which are generally ſubdivided into halves, and into quarters if the globe is large. Each tropic is 23½ degrees from the equator, and each polar circle 23½ degrees from its reſpective pole. Circles are drawn parallel to the equator, at every ten degrees diſtance from it on each ſide to the poles: theſe circles are called *parallels of latitude.* On large globes there are circles drawn perpendicularly through every tenth degree of the equator, interſecting each other at the poles: but on globes of or under a foot diameter, they are only drawn through every fifteenth degree of the equator; theſe circles are generally called *meridians,* ſometimes *circles of longitude,* and at other times *hour-circles.*

The globe is hung in a braſs ring, called the *braſen meridian*; and turns upon a wire in each pole ſunk half its thickneſs into one ſide of the meridian ring; by which means, *that* ſide of the ring divides the globe into two equal parts, called the *eaſtern* and *weſtern hemiſpheres*; as the equator divides it into two equal parts, called the *northern* and *ſouthern hemiſpheres.* This ring is divided into 360 equal parts or degrees, on the ſide wherein the axis of the globe turns. One half of theſe degrees are numbered, and reckoned, from the equator to the poles, where they end at 90: their uſe is to ſhew the latitudes of places. The degrees on the other half of the meridian ring, are numbered from the poles to the equator, where they end at 90: their uſe is to ſhew how to elevate either the north or ſouth pole above the horizon, according to the latitude of any given place, as it is north or ſouth of the equator.

The braſen meridian is let into two notches made in a broad flat ring, called the *wooden horizon*, the upper ſurface of which divides the globe into two equal parts, called the *upper* and *lower hemiſpheres*. One notch is in the north point of the horizon, and the other in the ſouth. On this horizon are ſeveral concentric circles, which contain the months and days of the year, the ſigns and degrees anſwering to the ſun's place for each month and day, and the 32 points of the compaſs.—The graduated ſide of the braſs meridian lies towards the eaſt ſide of the horizon, and ſhould be generally kept toward the perſon who works problems by the globes.

There is a ſmall *horary circle*, ſo fixed to the north part of the braſen meridian, that the wire in the north pole of the globe is in the center of that circle; and on the wire is an *index*, which goes over all the 24 hours of the circle, as the globe is turned round its axis. Sometimes there are two horary circles, one between each pole of the globe and the braſen meridian; which is the contrivance of the ingenious Mr. *Joſeph Harris*, maſter of the aſſay-office in the Tower of London; and makes it very convenient for putting the poles of the globe through the horizon, and for elevating the pole to ſmall latitudes and declinations of the ſun; which cannot be done where there is only one horary circle fixed to the outer edge of the braſen meridian.

There is a thin ſlip of braſs, called the *quadrant of altitude*, which is divided into 90 equal parts or degrees, anſwering exactly to ſo many degrees of the equator. It is occaſionally fixed to the uppermoſt point of the braſen meridian by a nut and ſcrew. The diviſions end at the nut, and the quadrant is turned round upon it.

As the globe has been ſeen by moſt people, and upon the figure of which, in a plate, neither the circles nor countries can be properly expreſſed, we judge it would ſignify very little to refer to a figure of it; and ſhall therefore only give ſome directions how to chooſe a globe, and then deſcribe its uſe.

Directions for chooſing of globes.

1. See that the papers be well and neatly paſted on the globes, which you may know, if the lines and circles thereon meet exactly, and continue all the way even and whole; the circles not breaking into ſeveral arches, nor the papers either coming ſhort, or lapping over one another.

2. See that the colours be tranſparent, and not laid too thick upon the globe to hide the names of places.

3. See that the globe hang evenly between the braſen meridian and the wooden horizon; not inclining either to one ſide or to the other.

4. See that the globe be as cloſe to the horizon and meridian as it conveniently may; otherwiſe, you will be too much puzzled to find againſt what part of the globe any degree of the meridian or horizon is.

5. See that the equinoctial line be even with the horizon all around, when the north or ſouth pole is elevated 90 degrees above the horizon.

6. See that the equinoctial line cuts the horizon in the eaſt and weſt points, in all elevations of the pole from 0 to 90 degrees.

7. See that the degree of the braſen meridian marked with 0, be exactly over the equinoctial line of the globe.

8. See that there be exactly half of the braſen meridian above the horizon; which you may know, if you bring any of the decimal diviſions on the meridian to the north point of the horizon, and find their complement to 90 in the ſouth point.

9. See that when the quadrant of altitude is placed as far from the equator, on the braſen meridian, as the pole is elevated above the horizon, the beginning of the degrees of the quadrant reaches juſt to the plane ſurface of the horizon.

10. See that whilſt the index of the hour-circle (by the motion of the globe) paſſes from one hour to another, 15 degrees of the equator paſs under the graduated edge of the braſen meridian.

11. See that the wooden horizon be made ſubſtantial and ſtrong: it being generally obſerved, that in moſt globes, the horizon is the firſt part that fails, on account of its having been made too ſlight.

Directions for uſing them.

In uſing the globes, keep the eaſt ſide of the horizon towards you (unleſs your problem requires the turning of it) which ſide you may know by the word Eaſt upon the horizon; for then you have the graduated ſide of the meridian towards you, the quadrant of altitude before you, and the globe divided exactly into two equal parts, by the graduated ſide of the meridian.

In working ſome problems, it will be neceſſary to turn the whole globe and horizon about, that you may look on the weſt ſide thereof; which turning will be apt to jog the ball ſo, as to ſhift away that degree of the globe which was before ſet to the horizon or meridian: to avoid which inconvenience, you may thruſt in the feather-end of a quill between the ball of the globe and the braſen meridian; which, without hurting the ball, will keep it from turning in the meridian, whilſt you turn the weſt ſide of the horizon towards you.

## PROBLEM I.

### *To find the * latitude and † longitude of any given place upon the globe.*

Turn the globe on its axis, until the given place comes exactly under that graduated ſide of the braſen meridian, on which the degrees are numbered from the equator; and obſerve what degree of the meridian the place then lies under; which is its latitude, north or ſouth, as the place is north or ſouth of the equator.

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* The latitude of a place is its diſtance from the equator, and is north or ſouth, as the place is north or ſouth of the equator. Thoſe who live at the equator have no latitude, becauſe it is there that the latitude begins.

† The longitude of a place is the number of degrees (reckoned upon the equator) that the meridian of the ſaid place is diſtant from the meridian of any other place from which we reckon, either eaſtward or weſtward, for 180 degrees, or half round the globe. The Engliſh reckon the longitude from the meridian of London, and the French now reckon it from the meridian of Paris. The meridian of that place, from which the longitude is reckoned, is called the *firſt meridian.* The places upon this meridian have no longitude, becauſe it is there that the longitude begins.

The globe remaining in this poſition, the degree of the equator, which is under the braſen meridian, is the longitude of the place (from the meridian of *London* on the *Engliſh* globes) which is eaſt or weſt, as the place lies on the eaſt or weſt ſide of the firſt meridian of the globe.—All the *Atlantic Ocean*, and *America*, is on the weſt ſide of the meridian of *London*; and the greateſt part of *Europe*, and of *Africa*, together with all *Aſia*, is on the eaſt ſide of the meridian of *London*, which is reckon the *firſt meridian* of the globe by the *Engliſh* geographers and aſtronomers.

## PROBLEM II.

*The longitude and latitude of a place being given, to find that place on the globe.*

Look for the given longitude in the equator (counting it eaſtward or weſtward from the firſt meridian, as it is mentioned to be eaſt or weſt;) and bring the point of longitude in the equator to the braſen meridian, on that ſide which is above the ſouth point of the horizon: then count from the equator, on the braſen meridian, to the degree of the given latitude, towards the north or ſouth pole, according as the latitude is north or ſouth; and under that degree of latitude on the meridian, you will have the place required.

## PROBLEM III.

*To find the difference of longitude, or difference of latitude, between any two given places.*

Bring each of theſe places to the braſen meridian, and ſee what its latitude is: the leſſer latitude ſubtracted from the greater, if both places are on the ſame ſide of the equator, or both latitudes added together, if they are on different ſides of it, is the difference of latitude required. And the number of degrees contained between theſe places, reckoned on the equator, when they are brought ſeparately under the braſen meridian, is their difference of longitude; if it be leſs than 180: but if more, let it be ſubtracted from 360, and the remainder is the difference of longitude required. Or,

Having brought one of the places to the braſen meridian, and ſet the hour-index to XII, turn the globe until the other place comes to the braſen meridian, and the number of hours and parts of an hour, paſt over by the index, will give the longitude in time; which may be eaſily reduced to degrees, by allowing 15 degrees for every hour, and one degree for every four minutes.

*N. B.* When we ſpeak of bringing any place to the braſen meridian, it is the graduated ſide of the meridian that is meant.

## PROBLEM IV.

*Any place being given, to find all thoſe places that have the ſame longitude or latitude with it.*

Bring the given place to the braſen meridian, then all thoſe places which lie under that ſide of the meridian, from pole to pole, have the ſame longitude with the given place. Turn the globe round its axis, and all thoſe places which paſs under the ſame degree of the meridian that the given place does, have the ſame latitude with that place.

Since all latitudes are reckoned from the equator, and all longitudes are reckoned from the firſt meridian, it is evident, that the point of the equator which is cut by the firſt meridian, has neither latitude nor longitude.—The greateſt latitude is 90 degrees, becauſe no place is more than 90 degrees from the equator. And the greater longitude is 180 degrees, becauſe no place is more than 180 degrees from the firſt meridian.

## PROBLEM V.

### *To find the* * antœci, † periœci, *and* ‡ antipodes, *of any given place.*

Bring the given place to the braſen meridian, and having found its latitude, keep the globe in that ſituation, and count the ſame number of degrees of latitude from the equator towards the

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[*] The *antœci* are thoſe people who live on the ſame meridian, and in equal latitudes, on different ſides of the equator. Being on the ſame meridian, they have the ſame hours; that is, when it is noon to the one, it is alſo noon to the other; and when it is mid-night to the one, it is alſo mid-night to the other, &c. Being on different ſides of the equator, they have different or oppoſite ſeaſons at the ſame time; the length of any day to the one is equal to the length of the night of that day to the other; and they have equal elevations of the different poles.

[†] The *periœci* are thoſe people who live on the ſame parallel of latitude, but on oppoſite meridians: ſo that though their latitude be the ſame, their longitude differs 180 degrees. By being in the ſame latitude, they have equal elevations of the ſame pole (for the elevation of the pole is always equal to the latitude of the place) the ſame length of days or nights, and the ſame ſeaſons. But being on oppoſite meridians, when it is noon to the one, it is mid-night to the other.

[‡] The *antipodes* are thoſe who live diametrically oppoſite to one another upon the globe, ſtanding with feet towards feet, on oppoſite meridians and parallels. Being on oppoſite ſides of the equator, they have oppoſite ſeaſons, winter to one, when it is ſummer to the other; being equally diſtant from the equator, they have the contrary poles equally elevated above the horizon; being on oppoſite meridians, when it is noon to the one, it muſt be midnight to the other; and as the ſun recedes from the one when he approaches to the other, the length of the day to one muſt be equal to the length of the night at the ſame time to the other.

contrary pole, and where the reckoning ends, you have the *antœci* of the given place upon the globe. Thoſe who live at the equator have no *antœci*.

The globe remaining in the ſame poſition, ſet the hour-index to the upper XII on the horary circle, and turn the globe until the index comes to the lower XII; then, the place which lies under the meridian, in the ſame latitude with the given place, is the *periœci* required. Thoſe who live at the poles have no *periœci*.

As the globe now ſtands (with the index at the lower XII) the *antipodes* of the given place will be under the ſame point of the braſen meridian where its *antœci* ſtood before. Every place upon the globe has its *antipodes*.

## PROBLEM VI.

### *To find the diſtance between any two places on the globe.*

Lay the graduated edge of the quadrant of altitude over both the places, and count the number of degrees intercepted between them on the quadrant; then multiply theſe degrees by 60, and the product will give the diſtance in geographical miles: but to find the diſtance in Engliſh miles, multiply the degrees by 69$\frac{1}{2}$, and the product will be the number of miles required. Or, take the diſtance betwixt any two places with a pair of compaſſes, and apply that extent to the equator; the number of degrees, intercepted between the points of the compaſſes, is the diſtance in degrees of a great circle [*]; which may be reduced either to geographical miles, or to Engliſh miles, as above.

## PROBLEM VII.

*A place on the globe being given, and its diſtance from any other place, to find all the other places upon the globe which are at the ſame diſtance from the given place.*

Bring the given place to the braſen meridian, and ſcrew the quadrant of altitude to the meridian,

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[*] Any circle that divides the globe into two equal parts, is called a *great circle*, as the equator or meridian. Any circle that divides the globe into two unequal parts (which every parallel of latitude does) is called a *leſſer circle*. Now, as every circle, whether great or ſmall, contains 360 degrees, and a degree upon the equator or meridian contains 60 geographical miles, it is evident, that a degree of longitude upon the equator, is longer than a degree of longitude upon any parallel of latitude, and muſt therefore contain a greater number of miles. So that, although all the degrees of latitude are equally long upon an artificial globe (though not preciſely ſo upon the earth itſelf) yet the degrees of longitude decreaſe in length, as the latitude increaſes, but not in the ſame proportion. The following table ſhews the length of a degree of longitude, in geographical miles, and hundredth parts of a mile, for every degree of latitude, from the equator to the poles: a degree on the equator being 60 geographical miles.

*Great circle.*

*Leſſer circle.*

ridian, directly over that place; then keeping the globe in that poſition, turn the quadrant quite round upon it, and the degree of the quadrant that touches the ſecond place, will paſs over all the other places which are equally diſtant with it from the given place.

This is the ſame as if one foot of a pair of compaſſes was ſet in the given place, and the other foot extended to the ſecond place, whoſe diſtance is known; for if the compaſſes be then turned round the firſt place as a center, the moving foot will go over all thoſe places which are at the ſame diſtance with the ſecond from it.

*A table ſhewing the number of miles in a degree of longitude, and in any given degree of latitude.*

| Deg. | Miles. Parts. | Deg. | Miles. Parts. | Deg. | Miles. Parts. | Deg. | Miles. Parts. | Deg. | Miles. Parts. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 59.99 | 19 | 56.73 | 37 | 47.92 | 55 | 34.41 | 73 | 17.54 |
| 2 | 59.96 | 20 | 56.38 | 38 | 47.28 | 56 | 33.55 | 74 | 16.53 |
| 3 | 59.92 | 21 | 56.02 | 39 | 46.63 | 57 | 32.68 | 75 | 15.52 |
| 4 | 59.85 | 22 | 55.63 | 40 | 45.97 | 58 | 31.79 | 76 | 14.31 |
| 5 | 59.77 | 23 | 55.23 | 41 | 45.28 | 59 | 30.90 | 77 | 13.50 |
| 6 | 59.67 | 24 | 54.81 | 42 | 44.59 | 60 | 30.00 | 78 | 12.48 |
| 7 | 59.56 | 25 | 54.38 | 43 | 43.88 | 61 | 29.09 | 79 | 11.45 |
| 8 | 59.42 | 26 | 53.93 | 44 | 43.16 | 62 | 28.17 | 80 | 10.42 |
| 9 | 59.26 | 27 | 53.46 | 45 | 42.43 | 63 | 27.24 | 81 | 9.38 |
| 10 | 59.09 | 28 | 52.96 | 46 | 41.68 | 64 | 26.30 | 82 | 8.35 |
| 11 | 58.89 | 29 | 52.47 | 47 | 40.92 | 65 | 25.36 | 83 | 7.32 |
| 12 | 58.69 | 30 | 51.96 | 48 | 40.15 | 66 | 24.41 | 84 | 6.28 |
| 13 | 58.46 | 31 | 51.43 | 49 | 39.36 | 67 | 23.44 | 85 | 5.24 |
| 14 | 58.22 | 32 | 50.88 | 50 | 38.57 | 68 | 22.48 | 86 | 4.20 |
| 15 | 57.95 | 33 | 50.32 | 51 | 37.76 | 69 | 21.50 | 87 | 3.15 |
| 16 | 57.67 | 34 | 49.74 | 52 | 36.94 | 70 | 20.52 | 88 | 2.10 |
| 17 | 57.38 | 35 | 49.15 | 53 | 36.11 | 71 | 19.53 | 89 | 1.05 |
| 18 | 57.06 | 36 | 48.54 | 54 | 35.27 | 72 | 18.54 | 90 | 0.00 |

## PROBLEM VIII.

*The hour of the day at any place being given, to find all thoſe places where it is noon at that time.*

Bring the given place to the braſen meridian, and ſet the index to the given hour; this done, turn the globe until the index points to the upper XII, and then, all the places that lie under the braſen meridian have noon at that time.

*N. B.* The upper XII always ſtands for noon; and when the bringing of any place to the braſen meridian is mentioned, the ſide of that meridian on which the degrees are reckoned from the equator is meant, unleſs the contrary ſide be mentioned.

## PROBLEM IX.

*The hour of the day at any place being given, to find what o'clock it then is at any other place.*

Bring the given place to the braſen meridian, and ſet the index to the given hour; then turn the globe, until the place where the hour is required comes to the meridian, and the index will point out the hour at that place.

## PROBLEM X.

*To find the ſun's place in the ecliptic, and his* declination for any given day of the year.*

Look on the horizon for the given day, and right againſt it you have the degree of the ſign in which the ſun is (or his place) on that day at noon. Find the ſame degree of that ſign in the ecliptic line upon the globe, and having brought it to the braſen meridian, obſerve what degree of the meridian ſtands over it; for that is the ſun's declination, reckoned from the equator.

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* The ſun's declination is his diſtance from the equinoctial in degrees, and is north or ſouth, as the ſun is between the equinoctial and the north or ſouth pole.

## PROBLEM XI.

*The day of the month being given, to find all thoſe places of the earth over which the ſun will paſs vertically on that day.*

Find the ſun's place in the ecliptic for the given day, and having brought it to the braſen meridian, obſerve what point of the meridian is over it; then, turning the globe round its axis, all thoſe places which paſs under that point of the meridian, are the places required: for as their latitude is equal, in degrees and parts of a degree, to the ſun's declination, the ſun muſt be directly over head to each of them at its reſpective noon.

## PROBLEM XII.

*A place being given in the * torrid zone, to find thoſe two days of the year, on which the Sun ſhall be vertical to that place.*

Bring the given place to the braſen meridian, and mark the degree of latitude that is exactly over it on the meridian; then turn the globe round its axis, and obſerve the two degrees of the ecliptic which paſs exactly under that degree of latitude: laſtly, find on the wooden horizon, the two days of the year in which the ſun is in thoſe degrees of the ecliptic, and they are the days required: for on them, and none elſe, the ſun's declination is equal to the latitude of the given place: and conſequently, he will then be vertical to it at noon.

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* The globe is divided into five zones; one torrid, two temperate, and two frigid. The *torrid zone* lies between the two tropics, and is 47 degrees in breadth, or 23½ on each ſide of the equator: the *temperate zones* lie between the tropics and polar circles, or from 23½ degrees of latitude, to 66½, on each ſide of the equator; and are each 43 degrees in breadth: the *frigid zones* are the ſpaces included within the polar circles, which being each 23½ degrees from their reſpective poles, the breadth of each of theſe zones is 47 degrees. As the ſun never goes without the tropics, he muſt every moment be vertical to ſome place or other in the torrid zone.

PRO-

## PROBLEM XIII.

*To find all thoſe places of the north frigid zone, where the ſun begins to ſhine conſtantly without ſetting, on any given day, from the 21ſt of March, to the 23d of September.*

On theſe two days, the ſun is in the equinoctial, and enlightens the globe exactly from pole to pole: therefore, as the earth turns round its axis, which terminates in the poles, every place upon it will go equally through the light and the dark, and ſo make equal day and night to all places of the earth. But as the ſun declines from the equator, towards either pole, he will ſhine juſt as many degrees round that pole, as are equal to his declination from the equator; ſo that no place within that diſtance of the pole will then go through any part of the dark, and conſequently the ſun will not ſet to it. Now, as the ſun's declination is northward, from the 21ſt of March to the 23d of September, he muſt conſtantly ſhine round the north pole all that time; and on the day that he is in the northern tropic, he ſhines upon the whole north frigid zone; ſo that no place within the north polar circle goes through any part of the dark on that day. Therefore, Having brought the ſun's place for the given day to the braſen meridian, and found his declination (by Prob. IX.) count as many degrees on the meridian, from the north pole, as are equal to the ſun's declination from the equator, and mark that degree from the pole where the reckoning ends; then, turning the globe round its axis, obſerve what places in the north frigid zone paſs directly under that mark; for they are the places required.

The like may be done for the ſouth frigid zone, from the 23d of September to the 21ſt of March, during which time the ſun ſhines conſtantly on the ſouth pole.

## PROBLEM XIV.

*To find the place over which the ſun is vertical, at any hour of a given day.*

Having found the ſun's declination for the given day (by Prob. IX.) mark it with a chalk on the braſen meridian; then bring the place where you are (ſuppoſe London) to the braſen meridian, and ſet the index to the given hour; which done, turn the globe on its axis, until the index points to XII at noon; and the place on the globe, which is then directly under the point of the ſun's declination marked upon the meridian, has the ſun that moment in the zenith, or directly over head.

## PROBLEM XV.

*The day and hour at any place being given, to find all thoſe places where the ſun is then riſing, or ſetting, or on the meridian: conſequently, all thoſe places which are enlightened at that time, and thoſe which are in the dark.*

This problem cannot be ſolved by any globe fitted up in the common way, with the hour-circle fixed upon the braſs meridian; unleſs the ſun be on or near ſome of the tropics on the given day. But by a globe fitted up according to Mr. *Joſeph Harris*'s invention (already mentioned) where the hour-circle lies on the ſurface of the globe, below the meridian, it may be ſolved for any day of the year, according to his method; which is as follows.

Having found the place to which the ſun is vertical at the given hour, if the place be in the northern hemiſphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of that place; if the place be in the ſouthern hemiſphere, elevate the ſouth pole accordingly; and bring the ſaid place to the braſen meridian. Then, all thoſe places which are in the weſtern ſemicircle of the horizon, have the ſun riſing to them at that time; and thoſe in the eaſtern ſemicircle have it ſetting: to thoſe under the upper ſemicircle of the braſs meridian, it is noon; and to thoſe under the lower ſemicircle, it is mid-night. All thoſe places which are above the horizon, are enlightened by the ſun, and have the ſun juſt as many degrees above them, as they themſelves are above the horizon: and this height may be known, by fixing the quadrant of altitude on the braſen meridian over the place to which the ſun is vertical; and then, laying it over any other place, obſerve what number of degrees on the quadrant are intercepted between the ſaid place and the horizon. In all thoſe places that are 18 degrees below the weſtern ſemicircle of the horizon, the morning twilight is juſt beginning; in all thoſe places that are 18 degrees below the eaſtern ſemicircle of the horizon, the evening twilight is ending; and all thoſe places that are lower than 18 degrees, have dark night.

If any place be brought to the upper ſemicircle of the braſen meridian, and the hour-index be ſet to the upper XII or noon, and then the globe be turned round eaſtward on its axis; when the place comes to the weſtern ſemicircle of the horizon, the index will ſhew the time of ſun-riſing at that place; and when the ſame place comes to the eaſtern ſemicircle of the horizon, the index will ſhew the time of ſun-ſet.

To thoſe places which do not go under the horizon, the ſun ſets not on that day: and to thoſe which do not come above it, the ſun does not riſe.

## PROBLEM XVI.

*The day and hour of a lunar eclipſe being given; to find all thoſe places of the earth to which it will be viſible.*

The moon is never eclipſed but when ſhe is full, and ſo directly oppoſite to the ſun, that the earth's ſhadow falls upon her. Therefore, whatever place of the earth the ſun is vertical to at that time, the moon muſt be vertical to the antipodes of that place; ſo that the ſun will be then viſible to one half of the earth, and the moon to the other.

Find the place to which the ſun is vertical at the given hour (by Prob. XIV.) elevate the pole to the latitude of that place, and bring the place to the upper part of the braſen meridian, as in the former problem: then, as the ſun will be viſible to all thoſe parts of the globe which are above the horizon, the moon will be viſible to all thoſe parts of the globe which are below it, at the time of her greateſt obſcuration.

But with regard to an eclipſe of the ſun, there is no ſuch thing as ſhewing to what places it will be viſible, with any degree of certainty, by a common globe; becauſe the moon's ſhadow covers but a ſmall portion of the earth's ſurface, and her latitude, or declination from the ecliptic, throws her ſhadow ſo variouſly upon the earth, that to determine the places on which it falls, recourſe muſt be had to long calculations.

## PROBLEM XVII.

### *To rectify the globe for the latitude, the * zenith, and the ſun's place.*

Find the latitude of the place (by Prob. I.) and if the place be in the northern hemiſphere, raiſe the north pole above the north point of the horizon, as many degrees (counted from the pole upon the braſen meridian) as are equal to the latitude of the place. If the place be in the ſouthern hemiſphere, raiſe the ſouth pole above the ſouth point of the horizon, as many degrees as are equal to the latitude. Then, turn the globe till the place comes under its latitude on the braſen meridian, and faſten the quadrant of altitude ſo, that the chamfered edge of its nut (which is even with the graduated edge) may be joined to the zenith, or point of latitude. This done, bring the ſun's place in the ecliptic for the given day (found by Prob. X.) to the graduated ſide of the braſen meridian, and ſet the hour-index to XII at noon, which is the uppermoſt XII on the hour-circle; and the globe will be rectified.

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* The *zenith*, in this ſenſe, is the higheſt point of the braſen meridian above the horizon; but in the proper ſenſe, it is that point of the heaven which is directly vertical to any given place, at any given inſtant of time.

*Remark.* The latitude of any place, is equal to the elevation of the neareſt pole of the heaven above the horizon of that place; and the poles of the heaven are directly over the poles of the earth, each 90 degrees from the equinoctial line. Let us be upon what place of the earth we will, if the limits of our view be not intercepted by hills, we ſhall ſee one half of the heaven, or 90 degrees every way round, from that point which is over our heads. Therefore, if we were upon the equator, the poles of the heaven would lie in our horizon, or limit of our view: if we go from the equator, towards either pole of the earth, we ſhall ſee the correſponding pole of the heaven riſing gradually above our horizon, juſt as many degrees as we have gone from the equator: and if we were at either of the earth's poles, the correſponding pole of the heaven would be directly over our head. Conſequently, the elevation or height of the pole in degrees above the horizon, is equal to the number of degrees that the place is from the equator.

## PROBLEM XVIII.

*The latitude of any place, not exceeding * $66\frac{1}{2}$ degrees, and the day of the month, being given; to find the time of ſun-riſing and ſetting, and conſequently the length of the day and night.*

Having rectified the globe for the latitude, and for the ſun's place on the given day (as directed in the preceding problem) bring the ſun's place in the ecliptic to the eaſtern ſide of the horizon, and the hour-index will ſhew the time of ſun-riſing; then turn the globe on its axis, until the ſun's place comes to the weſtern ſide of the horizon, and the index will ſhew the time of ſun-ſetting.

The hour of ſun-ſetting doubled, gives the length of the day; and the hour of ſun-riſing doubled, gives the length of the night.

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* All places whoſe latitude is more than $66\frac{1}{2}$ degrees, are in the frigid zones: and to thoſe places the ſun does not ſet in ſummer, for a certain number of diurnal revolutions, which occaſions this limitation of latitude.

## PROBLEM XIX.

*The latitude of any place, and the day of the month, being given; to find when the morning twilight begins, and the evening twilight ends, at that place.*

This problem is often limited: for, when the ſun does not go 18 degrees below the horizon, the twilight continues the whole night; and for ſeveral nights together in ſummer, between 49 and 66½ degrees of latitude: and the nearer to 66½, the greater is the number of theſe nights. But when it does begin and end, the following method will ſhew the time for any given day.

Rectify the globe, and bring the ſun's place in the ecliptic to the eaſtern ſide of the horizon; then mark that point of the ecliptic with a chalk which is in the weſtern ſide of the horizon, it being the point oppoſite to the ſun's place: this done, lay the quadrant of altitude over the ſaid point, and turn the globe eaſtward, keeping the quadrant at the chalk-mark, until it be juſt 18 degrees high on the quadrant; and the index will point out the time when the morning twilight begins: for the ſun's place will then be 18 degrees below the eaſtern ſide of the horizon. To find the time when the evening twilight ends, bring the ſun's place to the weſtern ſide of the horizon, and the point oppoſite to it, which was marked with the chalk, will be riſing in the eaſt: then, bring the quadrant over that point, and keeping it thereon, turn the globe weſtward, until the ſaid point be 18 degrees above the horizon on the quadrant, and the index will ſhew the time when the evening twilight ends; the ſun's place being then 18 degrees below the weſtern ſide of the horizon.

## PROBLEM XX.

*To find on what day of the year the ſun begins to ſhine conſtantly without ſetting, on any given place in the north frigid zone; and how long he continues to do ſo.*

Rectify the globe to the latitude of the place, and turn it about until ſome point of the ecliptic, between *Aries* and *Cancer*, coincides with the north point of the horizon where the braſen meridian cuts it: then find, on the wooden horizon, what day of the year the ſun is in that point of the ecliptic; for that is the day on which the ſun begins to ſhine conſtantly on the given place, without ſetting. This done, turn the globe until ſome point of the ecliptic, between *Cancer* and *Libra*, coincides with the north point of the horizon, where the braſen meridian cuts it; and find, on the wooden horizon, on what day the ſun is in that point of the ecliptic; which is the day that the ſun leaves off conſtantly ſhining on the ſaid place, and riſes and ſets to it as to other places on the globe. The number of natural days, or compleat revolutions of the ſun about the earth, between the two days above found, is the time that the ſun keeps conſtantly above the horizon without ſetting: for all that portion of the ecliptic, which lies between the two points which interſect the horizon in the very north, never ſets below it: and there is juſt as much of the oppoſite part of the ecliptic that never riſes; therefore, the ſun will keep as long conſtantly below the horizon in winter, as above it in ſummer.

Whoever conſiders the globe, will find, that all places of the earth do equally enjoy the benefit of the ſun, in reſpect of time, and are equally deprived of it. For, the days and nights are always equally long at the equator: and in all places that have latitude, the days at one time of the year are exactly equal to the nights at the oppoſite ſeaſon.

## PROBLEM XXI.

*To find in what latitude the ſun ſhines conſtantly without ſetting, for any length of time leſs than* * $182\frac{1}{2}$ *of our days and nights.*

Find a point in the ecliptic half as many degrees from the beginning of *Cancer* (either toward *Aries* or *Libra)* as there are † natural days in the time given; and bring that point to the north ſide of the braſen meridian, on which the degrees are numbered from the pole towards the equator: then, keep the globe from turning on its axis, and ſlide the meridian up or down, until the foreſaid point of the ecliptic comes to the north point of the horizon, and then, the elevation of the pole will be equal to the latitude required.

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* The reaſon of this limitation is, that $182\frac{1}{2}$ of our days and nights make half a year, which is the longeſt time that the ſun ſhines without ſetting, even at the poles of the earth.

† A natural day, contains the whole 24 hours: an artificial day, the time that the ſun is above the horizon.

PRO-

## PROBLEM XXII.

*The latitude of a place, not exceeding 66½ degrees, and the day of the month being given; to find the ſun's amplitude, or point of the compaſs on which he riſes or ſets.*

Rectify the globe, and bring the ſun's place to the eaſtern ſide of the horizon; then obſerve what point of the compaſs on the horizon ſtands right againſt the ſun's place, for that is his amplitude at riſing. This done, turn the globe weſtward, until the ſun's place comes to the weſtern ſide of the horizon, and it will cut the point of his amplitude at ſetting. Or, you may count the riſing amplitude in degrees, from the eaſt point of the horizon, to that point where the ſun's place cuts it; and the ſetting amplitude, from the weſt point of the horizon, to the ſun's place at ſetting.

## PROBLEM XXIII.

*The latitude, the ſun's place, and his * altitude, being given; to find the hour of the day, and the ſun's azimuth, or number of degrees that he is diſtant from the meridian.*

Rectify the globe, and bring the ſun's place to the given height upon the quadrant of altitude;

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* The ſun's altitude, at any time, is his height above the horizon at that time.

on the eaſtern ſide of the horizon, if the time be in the forenoon; or the weſtern ſide, if it be in the afternoon: then, the index will ſhew the hour; and the number of degrees in the horizon, intercepted between the quadrant of altitude and the ſouth point, will be the ſun's true azimuth at that time.

*N. B.* Always when the quadrant of altitude is mentioned in working any problem, the graduated edge of it is meant.

If this be done at ſea, and compared with the ſun's azimuth, as ſhewn by the compaſs, if they agree, the compaſs has no variation in that place: but if they differ, the compaſs does vary; and the variation is equal to this difference.

## PROBLEM XXIV.

*The latitude, hour of the day, and the ſun's place, being given; to find the ſun's altitude and azimuth.*

Rectify the globe, and turn it until the index points to the given hour; then lay the quadrant of altitude over the ſun's place in the ecliptic, and the degree of the quadrant cut by the ſun's place is his altitude at that time above the horizon; and the degree of the horizon cut by the quadrant is the ſun's azimuth, reckoned from the ſouth.

## PROBLEM XXV.

*The latitude, the ſun's altitude, and his azimuth being given; to find his place in the ecliptic, the day of the month, and hour of the day, though they had all been loſt.*

Rectify the globe for the latitude and * zenith, and ſet the quadrant of altitude to the given azimuth in the horizon; keeping it there, turn the globe on its axis until the ecliptic cuts the quadrant in the given altitude: that point of the ecliptic which cuts the quadrant there, will be the ſun's place; and the day of the month anſwering thereto, will be found over the like place of the ſun on the wooden horizon. Keep the quadrant of altitude in that poſition, and having brought the ſun's place to the braſen meridian, and the hour-index to XII at noon, turn back the globe, until the ſun's place cuts the quadrant of altitude again, and the index will ſhew the hour.

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* By rectifying the globe for the zenith, is meant ſcrewing the quadrant of altitude to the given latitude on the braſs meridian.

Any two points of the ecliptic which are equidiſtant from the beginning of *Cancer* or of *Capricorn,* will have the ſame altitude and azimuth at the ſame hour, though the months be different; and therefore it requires ſome care in this problem, not to miſtake both the month, and the day of the month; to avoid which, obſerve, that from the 20th of March to the 21ſt of June, that part of the ecliptic which is between the beginning of *Aries* and beginning of *Cancer* is to be uſed: from the 21ſt of June to the 23d of September, between the beginning of *Cancer* and beginning of *Libra*: from the 23d of September to the 21ſt of December, between the beginning of *Libra* and the beginning of *Capricorn*; and from the 21ſt of December to the 20th of March, between the beginning of *Capricorn* and beginning of *Aries.* And as one can never be at a loſs to know in what quarter of the year he takes the ſun's altitude and azimuth, the above caution with regard to the quarters of the ecliptic, will keep him right as to the month and day thereof.

## PROBLEM XXVI.

### *To find the length of the longeſt day at any given place.*

If the place be on the north ſide of the equator (find its latitude by Prob. I.) and elevate the north pole to that latitude; then, bring the beginning of *Cancer* ♋ to the braſen meridian, and ſet the hour-index to XII at noon. But if the given place be on the ſouth ſide of the equator, elevate the ſouth pole to its latitude, and bring the beginning of *Capricorn* ♑ to the braſs meridian, and the hour-index to XII. This done, turn the globe weſtward, until the beginning of *Cancer* or *Capricorn* (as the latitude is north or ſouth) comes to the horizon; and the index will then point out the time of ſun-ſetting, for it will have gone over all the afternoon hours, between mid-day and ſun-ſet; which length of time being doubled, will give the whole length of the day, from ſun-riſing to ſun-ſetting. For, in all latitudes, the ſun riſes as long before mid day, as he ſets after it.

## PROBLEM XXVII.

### *To find in what latitude the longeſt day is of any given length leſs than 24 hours.*

If the latitude be north, bring the beginning of *Cancer* to the braſen meridian, and elevate the north pole to about 66½ degrees; but if the latitude be ſouth, bring the beginning of *Capricorn* to the meridian, and elevate the ſouth pole to about 66½ degrees, becauſe the longeſt day in north latitude, is when the ſun is in the firſt point of *Cancer*; and in ſouth latitude, when he is in the firſt point of *Capricorn.* Then ſet the hour-index to XII at noon, and turn the globe weſtward, until the index points at half the number of hours given; which done, keep the globe from turning on its axis, and ſlide the meridian down in the notches, until the aforeſaid point of the ecliptic (viz. *Cancer* or *Capricorn)* comes to the horizon; then, the elevation of the pole will be equal to the latitude required.

## PROBLEM XXVIII.

*The latitude of any place, not exceeding 66½ degrees, being given; to find in what * climate the place is.*

Find the length of the longeſt day at the given place by Prob. XXVI. and whatever be the number of hours whereby it exceedeth twelve, double that number, and the ſum will give the climate in which the place is.

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* A *Climate,* from the equator to either of the polar circles, is a tract of the earth's ſurface, included between two ſuch parallels of latitude, that the length of the longeſt day in the one exceeds that in the other by half an hour; but from the polar circles to the poles, where the ſun keeps along above the horizon without ſetting, each climate differs a whole month from the one next to it. There are twenty-four climates between the equator and each of the polar circles; and ſix from each polar circle to its reſpective pole.

## PROBLEM XXIX.

*The latitude and the day of the month, being given; to find the hour of the day when the ſun ſhines.*

Set the wooden horizon truly level, and the braſen meridian due north and ſouth by a mariner's compaſs: then, having rectified the globe, ſtick a ſmall ſewing-needle into the ſun's place in the ecliptic, perpendicular to that part of the ſurface of the globe: this done, turn the globe on its axis, until the needle comes to the braſen meridian, and ſet the hour-index to XII at noon; then, turn the globe on its axis, until the needle points exactly towards the ſun (which it will do when it caſts no ſhadow on the globe) and the index will ſhew the hour of the day.

## PROBLEM XXX.

*A pleaſant way of ſhewing all thoſe places of the earth which are enlightened by the ſun, and alſo the time of the day when the ſun ſhines.*

Take the terreſtrial ball out of the wooden horizon, and alſo out of the braſen meridian;

then ſet it upon a pedeſtal in ſun-ſhine, in ſuch a manner, that its north pole may point directly towards the north pole of the heaven, and the meridian of the place where you are be directly towards the ſouth. Then, the ſun will ſhine upon all the like places of the globe, that he does on the real earth, riſing to ſome when he is ſetting to others ; as you may perceive by that part where the enlightened half of the globe is divided from the half in the ſhade, by the boundary of the light and darkneſs : all thoſe places, on which the ſun ſhines, at any time, having day ; and all thoſe, on which he does not ſhine, having night.

If a narrow ſlip of paper be put round the equator, and divided into 24 equal parts, beginning at the meridian of your place, and the hours be ſet to thoſe diviſions in ſuch a manner, that one of the VI's may be upon your meridian ; the ſun being upon that meridian at noon, will then ſhine exactly to the two XII's ; and at one o'clock to the two I's, &c. So that the place, where the enlightened half of the globe is parted from the ſhaded half, in this circle of hours, will ſhew the hour of the day.

We ſhall here add the following obſervations on the Terreſtrial Globe, and then proceed to the Uſe of the Celeſtial Globe, *&c.*

1. *The latitude of any place is equal to the elevation of the pole above the horizon of that place, and the elevation of the equator is equal to the complement of the latitude, that is, to what the latitude wants of* 90 *degrees.*

2. *Thoſe places which lie on the equator, have no latitude, it being there that the latitude begins; and thoſe places which lie on the firſt meridian have no longitude, it being there that the longitude begins. Conſequently, that particular place of the earth where the firſt meridian interſects the equator, has neither longitude nor latitude.*

3. *In all places of the earth, except the poles, all the points of the compaſs may be diſtinguiſhed in the horizon: but from the north pole, every place is ſouth; and from the ſouth pole, every place is north. Therefore, as the ſun is conſtantly above the horizon of each pole for half a year in its turn, he cannot be ſaid to depart from the meridian of either pole for half a year together. Conſequently, at the north pole it may be ſaid to be noon every moment for half a year; and let the winds blow from what part they will, they muſt always blow from the ſouth; and at the ſouth pole, from the north.*

4. *Becauſe one half of the ecliptic is above the horizon of the pole, and the ſun, moon and planets, move in (or nearly in) the ecliptic; they will all*

*riſe and ſet to the poles. But, becauſe the ſtars never change their declinations from the equator (at leaſt not ſenſibly in one age) thoſe which are once above the horizon of either pole, never ſet below it; and thoſe which are once below it, never riſe.*

5. *All places of the earth do equally enjoy the benefit of the ſun, in reſpect of time, and are equally deprived of it.*

6. *All places upon the equator have their days and nights equally long, that is,* 12 *hours each, at all times of the year. For although the ſun declines alternately, from the equator towards the north and towards the ſouth, yet, as the horizon of the equator cuts all the parallels of latitude and declination in halves, the ſun muſt always continue above the horizon for one half a diurnal revolution about the earth, and for the other half below it.*

7. *When the ſun's declination is greater than the latitude of any place, upon either ſide of the equator, the ſun will come twice to the ſame azimuth or point of the compaſs in the forenoon at that place; and twice to a like azimuth in the afternoon; that is, he will go twice back every day, whilſt his declination continues to be greater than the latitude. Thus, ſuppoſe the globe rectified to the latitude of Barbadoes, which is* 13 *degrees north; and the ſun to be any where in the ecliptic, between the middle of Taurus and middle of Leo; if the quadrant of altitude*

*altitude be ſet to about* [*] 18 *degrees north of the eaſt in the horizon, the ſun's place be marked with a chalk upon the ecliptic, and the globe be then turned weſtward on its axis, the ſaid mark will riſe in the horizon a little to the north of the quadrant, and thence aſcending, it will croſs the quadrant towards the ſouth; but before it arrives at the meridian, it will croſs the quadrant again, and paſs over the meridian northward of Barbadoes And if the quadrant be ſet about* 18 *degrees north of the weſt, the ſun's place will croſs it twice, as it deſcends from the meridian towards the horizon, in the afternoon.*

8. *In all places of the earth between the equator and poles, the days and nights are equally long,* viz. 12 *hours each, when the ſun is in the equinoctial; for, in all elevations of the pole, ſhort of* 90 *degrees (which is the greateſt) one half of the equator or equinoctial will be above the horizon, and the other half below it.*

9. *The days and nights are never of an equal length at any place between the equator and polar circles, but when the ſun enters the ſigns ♈ Aries and ♎ Libra. For in every other part of the ecliptic, the circle of the ſun's daily motion is divided into two unequal parts by the horizon.*

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[*] From the middle of Gemini to the middle of Cancer, the quadrant may be ſet 20 degrees.

10. *The nearer that any place is to the equator, the leſs is the difference between the length of the days and nights in that place; and the more remote, the contrary. The circles which the ſun deſcribes in the heaven every 24 hours, being cut more nearly equal in the former caſe, and more unequally in the latter.*

11. *In all places lying upon any given parallel of latitude, however long or ſhort the day or night be at any one of theſe places, at any time of the year, it is then of the ſame length at all the reſt; for in turning the globe round its axis (when rectified according to the ſun's declination) all theſe places will keep equally long above or below the horizon.*

12. *The ſun is vertical twice a year to every place between the tropics; to thoſe under the tropics, once a year, but never any where elſe. For, there can be no place between the tropics, but that there will be two points in the ecliptic, whoſe declination from the equator is equal to the latitude of that place; and but one point of the ecliptic which has a declination equal to the latitude of places on the tropic which that point of the ecliptic touches; and as the ſun never goes without the tropics, he can never be vertical to any place that lies without them.*

13. *To all places in the* * *torrid zone, the duration of the twilight is leaſt, becauſe the ſun's daily motion is the moſt perpendicular to the horizon. In the frigid* † *zones, greateſt; becauſe the ſun's daily motion is nearly parallel to the horizon; and therefore he is the longer of getting* 18 *degrees below it (till which time the twilight always continues.) And in the* ‡ *temperate zones it is at a medium between the two, becauſe the obliquity of the ſun's daily motion is ſo.*

14. *In all places lying exactly under the polar circles, the ſun, when he is in the neareſt tropic, continues* 24 *hours above the horizon without ſetting; becauſe no part of that tropic is below their horizon. And when the ſun is in the fartheſt tropic, he is for the ſame length of time without riſing; becauſe no part of that tropic is above their horizon. But, at all other times of the year, he riſes and ſets there, as in other places; becauſe all the circles that can be drawn parallel to the equator, between the tropics, are more or leſs cut by the horizon, as they are farther from, or nearer to, that tropic which is all above the horizon: and when the ſun is not in either of the tropics, his diurnal courſe muſt be in one or other of theſe circles.*

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* Between the tropics.

† Between the polar circles and poles.

‡ Between the tropics and polar circles.

15. *To all places in the northern hemiſphere, from the equator to the polar circle, the longeſt day ſhorteſt night is when the ſun is in the northern tropic; and the ſhorteſt day and longeſt night is when the ſun is in the ſouthern tropic; becauſe no circle of the ſun's daily motion is ſo much above the horizon, and ſo little below it, as the northern tropic; and none ſo little above it, and ſo much below it, as the ſouthern. In the ſouthern hemiſphere the contrary.*

16. *In all places between the polar circles and poles, the ſun appears for ſome number of days (or rather diurnal revolutions) without ſetting; and at the oppoſite time of the year without riſing; becauſe ſome part of the ecliptic never ſets in the former caſe, and as much of the oppoſite part never riſes in the latter. And the nearer unto, or the more remote from the pole, theſe places are, the longer or ſhorter is the ſun's continual preſence or abſence.*

17. *If a ſhip ſets out from any port, and ſails round the earth eaſtward to the ſame port again, let her take what time ſhe will to do it in, the people in that ſhip, in reckoning their time, will gain one compleat day at their return, or count one day more than thoſe who reſide at the ſame port; becauſe, by going contrary to the ſun's diurnal motion, and being forwarder every evening than they were in the morning, their horizon will get ſo much the ſooner above*

*above the ſetting ſun, than if they had kept for a whole day at any particular place. And thus, by cutting off a part proportionable to their own motion, from the length of every day, they will gain a compleat day of that ſort at their return; without gaining one moment of abſolute time more than is elapſed during their courſe, to the people at the port. If they ſail weſtward, they will reckon one day leſs than the people do who reſide at the ſaid port, becauſe by gradually following the apparent diurnal motion of the ſun, they will keep him each particular day ſo much longer above their horizon, as anſwers to that day's courſe; and by that means, they cut off a whole day in reckoning, at their return, without loſing one moment of abſolute time.*

*Hence, if two ſhips ſhould ſet out at the ſame time from any port, and ſail round the globe, one eaſtward and the other weſtward, ſo as to meet at the ſame port on any day whatever; they will differ two days in reckoning their time at their return. If they ſail twice round the earth, they will differ four days; if thrice, then ſix, &c.*

# THE USE OF THE

# CELESTIAL GLOBE,

# AND

# ARMILLARY SPHERE.

The *celeſtial globe.*

HAVING done for the preſent with the terreſtrial globe, we ſhall proceed to the uſe of the celeſtial; firſt premiſing, that as the equator, ecliptic, tropics, polar circles, horizon, and braſen meridian, are exactly alike on both globes, all the former problems concerning the ſun are ſolved the ſame way by both globes. The method alſo of rectifying the celeſtial globe is the ſame as rectifying the terreſtrial, viz. Elevate the pole according to the latitude of your place, then ſcrew the quadrant of altitude to the zenith, on the braſs meridian; bring the ſun's place in the ecliptic to the graduated edge of the braſs meridian, on the ſide which is above the ſouth point of the

To rectify it.

wooden horizon, and ſet the hour-index to the uppermoſt XII, which ſtands for noon.

*N. B.* The ſun's place for any day of the year ſtands directly over that day on the horizon of the celeſtial globe, as it does on that of the terreſtrial.

*Latitude* and *longitude* of the *ſtars.*

The *latitude* and *longitude* of the ſtars, or of all other celeſtial phenomena, are reckoned in a very different manner from the latitude and longitude of places on the earth: for all terreſtrial latitudes are reckoned from the equator; and longitudes from the meridian of ſome remarkable place, as of London by the Engliſh, and of Paris by the French; though moſt of the French maps begin their longitude at the meridian of the iſland *Ferro.*——But the aſtronomers of all nations agree in reckoning the *latitudes* of the moon, ſtars, planets, and comets, from the *ecliptic*; and their *longitudes* from the * *equinoctial colure,* in that ſemicircle of it which cuts the ecliptic at the beginning of *Aries* ♈; and thence eaſtward, quite round, to the ſame ſemicircle again. Conſequently thoſe ſtars which lie

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*Colures.*

* *The great circle* that paſſes through the *equinoctial points* at the beginning of ♈ and ♎, and through the poles of the world (which are two oppoſite points, each 90 degrees from the equinoctial) called the *equinoctial colure:* and the *great circle* that paſſes through the *beginning of* ♋ and ♑, and alſo through the poles of the ecliptic, and poles of the world, is called the *ſolſtitial colure.*

between the equinoctial and the northern half of the ecliptic, have north declination and ſouth latitude; thoſe which lie between the equinoctial and the ſouthern half of the ecliptic, have ſouth declination and north latitude; and all thoſe which lie between the tropics and poles, have their declinations and latitudes of the ſame denomination.

There are ſix great circles on the celeſtial globe, which cut the ecliptic perpendicularly, and meet in two oppoſite points in the polar circles; which points are each ninety degrees from the ecliptic, and are called its poles. Theſe polar points divide thoſe circles into 12 ſemicircles; which cut the ecliptic at the beginnings of the 12 ſigns. They reſemble ſo many meridians on the terreſtrial globe; and as all places which lie under any particular meridian ſemicircle on that globe, have the ſame longitude, ſo all thoſe points of the heaven, through which any one of the above ſemicircles are drawn, have the ſame longitude.—And as the greateſt latitudes on the earth are at the north and ſouth poles of the earth, ſo the greateſt latitudes in the heaven, are at the north and ſouth poles of the ecliptic.

In order to diſtinguiſh the ſtars, with regard to their ſituations and poſitions in the heaven, the antients divided the whole viſible firmament of ſtars into particular ſyſtems, which they called *Conſtellations.*

called *conſtellations*; and digeſted them into the forms of ſuch animals as are delineated upon the celeſtial globe. And thoſe ſtars which lie between the figures of thoſe imaginary animals, and could not be brought within the compaſs of any of them, were called *unformed ſtars.*

Becauſe the moon and all the planets were obſerved to move in circles or orbits which croſs the ecliptic (or line of the ſun's path) at ſmall angles, and to be on the north ſide of the ecliptic for one half of their courſe round the heaven of ſtars, and on the ſouth ſide of it for the other half, but never to go quite 8 degrees from it on either ſide, the antients diſtinguiſhed that ſpace by two leſſer circles, parallel to the ecliptic (one on each ſide) at 8 degrees diſtance from it. And the ſpace included between theſe circles, they called the *zodiac*, becauſe moſt of the 12 conſtellations placed therein reſemble ſome living creature.——Theſe conſtellations are, 1. *Aries* ♈, the ram; 2. *Taurus* ♉, the bull; 3. *Gemini* ♊, the twins; 4. *Cancer* ♋, the crab; 5. *Leo* ♌, the lion; 6. *Virgo* ♍, the virgin; 7. *Libra* ♎, the balance; 8. *Scorpio* ♏, the ſcorpion; 9. *Sagittarius* ♐, the archer; 10. *Capricornus* ♑, the goat; 11. *Aquarius* ♒, the water-bearer; and 12. *Piſces* ♓, the fiſhes.

Its ſigns, or diviſions.

Remark.

It is to be obſerved, that in the infancy of aſtronomy, theſe twelve conſtellations ſtood at or near the places of the ecliptic, where the above characteriſtics are marked upon the globe: but now, each conſtellation has got a whole ſign forwarder, on account of the receſſion of the equinoctial points from their former places. So that the conſtellation of *Aries*, is now into the former place of *Taurus*; that of *Taurus*, into the former place of *Gemini*; and ſo on.

The ſtars appear of different magnitudes to the eye; probably becauſe they are at different diſtances from us. Thoſe which appear brighteſt and largeſt, are called *ſtars of the firſt magnitude*; the next to them in ſize and luſtre, are called *ſtars of the ſecond magnitude*; and ſo on to the *ſixth*, which are the ſmalleſt that can be diſcerned by the bare eye.

Some of the moſt remarkable ſtars have names given them, as *Caſtor* and *Pollux* in the heads of the *Twins*, *Sirius* in the mouth of the *Great Dog*, *Procyon* in the ſide of the *Little Dog*, *Rigel* in the left foot *Orion*, *Arcturus* near the right thigh of *Bootes*, &c.

Theſe things being premiſed, which I think are all that the young *Tyro* need be acquainted with, before he begins to work any problem by this globe, we ſhall now proceed to the moſt uſeful of thoſe problems; omitting ſeveral which are of little or no conſequence.

## PROBLEM I.

*To find the* * *right aſcenſion and* † *declination of the ſun, or any fixed ſtar.*

Bring the ſun's place in the ecliptic to the braſen meridian, then that degree in the equinoctial which is cut by the meridian, is the ſun's *right aſcenſion*; and that degree of the meridian which is over the ſun's place, is his *declination*. Bring any fixed ſtar to the meridian, and its *right aſcenſion* will be cut by the meridian in the equinoctial; and the degree of the meridian that ſtands over it, is its *declination*.

So that *right aſcenſion* and *declination*, on the celeſtial globe, are found in the ſame manner as *longitude* and *latitude* on the terreſtrial.

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* The degree of the equinoctial, reckoned from the beginning of *Aries* that comes to the meridian with the ſun or ſtar, is its *right aſcenſion*.

† The diſtance of the ſun or ſtar in degrees from the equinoctial towards either of the poles, north or ſouth, is its declination, which is north or ſouth accordingly.

PRO-

## PROBLEM II.

*To find the latitude and longitude of any ſtar.*

If the given ſtar be on the north ſide of the ecliptic, place the 90th degree of the quadrant of altitude on the north pole of the ecliptic, where the twelve ſemicircles meet; which divide the ecliptic into the 12 ſigns: but if the ſtar be on the ſouth ſide of the ecliptic, place the 90th degree of the quadrant on the ſouth pole of the ecliptic: keeping the 90th degree of the quadrant on the proper pole, turn the quadrant about, until its graduated edge cuts the ſtar: then, the number of degrees in the quadrant, between the ecliptic and the ſtar, is its latitude; and the degree of the ecliptic cut by the quadrant is the ſtar's longitude, reckoned according to the ſign in which the quadrant then is.

## PROBLEM III.

*To repreſent the face of the ſtarry firmament, as ſeen from any given place of the earth, at any hour of the night.*

Rectify the celeſtial globe for the given latitude, the zenith, and ſun's place, in every reſpect, as taught by the 17th problem, for the terreſtrial; and turn it about, until the index points to the given hour: then, the upper hemiſphere of the globe will repreſent the viſible half of the heaven for that time: all the ſtars upon the globe being then in ſuch ſituations, as exactly correſpond to thoſe in the heaven. And if the globe be placed duly north and ſouth, by means of a ſmall ſea-compaſs, every ſtar on the globe will point toward the like ſtar in the heaven: by which means, the conſtellations and remarkable ſtars may be eaſily known. All thoſe ſtars which are in the eaſtern ſide of the horizon, are then riſing in the eaſtern ſide of the heaven; all in the weſtern, are ſetting in the weſtern ſide; and all thoſe under the upper part of the braſen meridian, between the ſouth point of the horizon and the north pole, are at their greateſt altitude, if the latitude of the place be north: but if the latitude be ſouth, thoſe ſtars which lie under the upper part of the meridian, between the north point of the horizon and the ſouth pole, are at their greateſt altitude.

## PROBLEM IV.

*The latitude of the place, and day of the month, being given; to find the time when any known ſtar will riſe, or be upon the meridian, or ſet.*

Having rectified the globe, turn it about until the given ſtar comes to the eaſtern ſide of the horizon, and the index will ſhew the time of the ſtar's riſing; then turn the globe weſtward, and when the ſtar comes to the braſen meridian, the index will ſhew the time of the ſtar's coming to the meridian of your place; laſtly, turn on, until the ſtar comes to the weſtern ſide of the horizon, and the index will ſhew the time of the ſtar's ſetting.

*N. B.* In northern latitudes, thoſe ſtars which are leſs diſtant from the north pole, than the quantity of its elevation above the north point of the horizon, never ſet; and thoſe which are leſs diſtant from the ſouth pole, than the number of degrees by which it is depreſſed below the horizon, never riſe: and *vice verſa* in ſouthern latitudes.

## PROBLEM V.

*To find at what time of the year a given ſtar will be upon the meridian, at a given hour of the night.*

Bring the given ſtar to the upper ſemicircle of the braſs meridian, and ſet the index to the given hour; then turn the globe, until the index points to XII at noon, and the upper ſemicircle of the meridian will then cut the ſun's place, anſwering to the day of the year ſought; which day may be eaſily found againſt the like place of the ſun among the ſigns on the wooden horizon.

## PROBLEM VI.

*The latitude, day of the month, and * azimuth of any known ſtar being given; to find the hour of the night.*

Having rectified the globe for the latitude, zenith, and ſun's place; lay the quadrant of altitude to the given degree of azimuth in the horizon: then turn the globe on its axis, until the ſtar comes to the graduated edge of the quadrant; and when it does, the index will point out the hour of the night.

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* The number of degrees that the ſun, moon, or any ſtar, is from the meridian, either to the eaſt or weſt, is called its *azimuth*.

## PROBLEM VII.

*The latitude of the place, the day of the month, and altitude* * *of any known ſtar, being given; to find the hour of the night.*

Rectify the globe as in the former problem, gueſs at the hour of the night, and turn the globe until the index points at the ſuppoſed hour; then lay the graduated edge of the quadrant of altitude over the known ſtar, and if the degree of the ſtar's height in the quadrant upon the globe, anſwers exactly to the degree of the ſtar's obſerved altitude in the heaven, you have gueſſed exactly: but if the ſtar on the globe is higher or lower than it was obſerved to be in the heaven, turn the globe backwards or forwards, keeping the edge of the quadrant upon the ſtar, until its center comes to the obſerved altitude in the quadrant; and then, the index will ſhew the true time of the night.

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* The number of degrees that the ſtar is above the horizon, as obſerved by means of a common quadrant, is called its *altitude.*

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## PROBLEM VIII.

*An eaſy method for finding the hour of the night by any known ſtars, without knowing either their altitude or azimuth; and then, of finding both their altitude and azimuth, and thereby the true meridian.*

Tie one end of a thread to a common muſket bullet; and, having rectified the globe as above, hold the other end of the thread in your hand, and carry it ſlowly round betwixt your eye and the ſtarry heaven, until you find it cuts any two known ſtars at once. Then, gueſſing at the hour of the night, turn the globe until the index points to that time in the hour-circle; which done, lay the graduated edge of the quadrant over any one of theſe two ſtars on the globe, which the thread cut in the heaven. If the ſaid edge of the quadrant cuts the other ſtar alſo, you have gueſſed the time exactly; but if it does not, turn the globe ſlowly backwards or forwards, until the quadrant (kept upon either ſtar) cuts them both through their centers: and then, the index will point out the exact time of the night; the degree of the horizon, cut by the quadrant, will be the true azimuth of both theſe ſtars from the ſouth; and the ſtars themſelves will cut their true altitude in the quadrant. At which moment, if a common azimuth compaſs be ſo ſet upon a floor or level pavement, that theſe ſtars in the heaven may have the ſame bearing upon it (allowing for the variation of the needle) as the quadrant of altitude has in the wooden horizon of the globe, a thread extended over the north and ſouth points of that compaſs will be directly in the plane of the meridian: and if a line be drawn upon the floor or pavement, along the courſe of the thread, and an upright wire be placed in the ſouthmoſt end of the line, the ſhadow of the wire will fall upon that line, when the ſun is on the meridian, and ſhines upon the pavement.

## PROBLEM IX.

*To find the place of the moon, or of any planet, and thereby to ſhew the time of its riſing, ſouthing, and ſetting.*

Seek in *Parker*'s or *Weaver*'s Ephemeris the * geocentric place of the moon or planet in the ecliptic, for the given day of the month; and, according to its longitude and latitude, as ſhewn by the Ephemeris, mark the ſame with a chalk upon the globe. Then, having rectified the globe, turn it round its axis weſtward; and as the ſaid mark comes to the eaſtern ſide of the horizon, to the braſen meridian, and to the weſtern ſide of the horizon, the index will ſhew at what time the planet riſes, comes to the meridian, and ſets, in the ſame manner as it would do for a fixed ſtar.

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* The place of the moon or planet, as ſeeen from the earth, is called its geocentric place.

## PROBLEM X.

*To explain the phenomena of the harveſt-moon.*

In order to do this, we muſt premiſe the following things. 1. That as the ſun goes only once a year round the ecliptic he can be but once a year in any particular point of it: and that his motion is almoſt a degree every 24 hours at a mean rate. 2. That as the moon goes round the ecliptic once in 27 days and 8 hours, ſhe advances 13$\frac{1}{6}$ degrees in it, every day at a mean rate. 3. That as the ſun goes through part of the ecliptic in the time the moon goes round it, the moon cannot at any time be either in conjunction with the ſun, or oppoſite to him, in that part of the ecliptic where ſhe was ſo the laſt time before; but muſt travel as much forwarder, as the ſun has advanced in the ſaid time; which being 29$\frac{1}{2}$ days, makes almoſt a whole ſign. Therefore, 4. The moon can be but once a year oppoſite to the ſun, in any particular part of the ecliptic. 5. That the moon is never full but when ſhe is oppoſite to the ſun, becauſe at no other time can we ſee all that half of her, which the ſun enlightens. 6. That when any point of the ecliptic riſes, the oppoſite point ſets. Therefore, when the moon is oppoſite to the ſun, ſhe muſt riſe at * ſun-ſet. 7. That the different ſigns of the ecliptic riſe at very different angles or degrees of obliquity with the horizon, eſpecially in conſiderable latitudes; and that the ſmaller this angle is, the greater is the portion of the ecliptic that riſes in any ſmall part of time; and *vice verſa.* 8. That, in northern latitudes, no part of the ecliptic riſes at ſo ſmall an angle with the horizon, as *Piſces* and *Aries* do; therefore, a greater portion of the ecliptic riſes in one hour, about theſe ſigns, than about any of the reſt. 9. That the moon can never be full in *Piſces* and *Aries* but in our autumnal months, for at no other time of the year is the ſun in the oppoſite ſigns *Virgo* and *Libra.*

Theſe things premiſed, take 13⅙ degrees of the ecliptic in your compaſſes, and, beginning at *Piſces,* carry that extent all round the ecliptic, marking the places with a chalk, where the points of the compaſſes ſucceſſively fall. So you will have the moon's daily motion marked out for one compleat revolution in the ecliptic (according to § 2 of the laſt paragraph.)

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* This is not always ſtrictly true, becauſe the moon does not keep in the ecliptic, but croſſes it twice every month. However the difference need not be regarded in a general explanation.

Rectify the globe for any conſiderable northern latitude, (as ſuppoſe that of London) and then, turning the globe round its axis, obſerve how much of the hour-circle the index has gone over, at the riſing of each particular mark on the ecliptic; and you will find that ſeven of the marks (which take in as much of the ecliptic as the moon goes through in a week) will all riſe ſucceſſively about *Piſces* and *Aries*, in the time that the index goes over two hours. Therefore, whilſt the moon is in *Piſces* and *Aries*, ſhe will not differ in general above two hours in her riſing for a whole week. But if you take notice of the marks on the oppoſite ſigns, *Virgo* and *Libra*, you will find that ſeven of them take nine hours to riſe; which ſhews, that when the moon is in theſe two ſigns, ſhe differs nine hours in her riſing within the compaſs of a week. And ſo much later as every mark is riſing than the one that roſe next before it, ſo much later will the moon be of riſing any day, than ſhe was on the day before, in the correſponding part of the heaven. The marks about *Cancer* and *Capricorn* riſe with a mean difference of time between thoſe about *Aries* and *Libra*.

Now, although the moon is in *Piſces* and *Aries* every month, and therefore muſt riſe in thoſe ſigns within the ſpace of two hours later for a whole week, or only about 17 minutes later every day than ſhe did on the former; yet ſhe is never full in theſe ſigns, but in our autumnal months, *Auguſt* and *September*, when the ſun is in *Virgo* and *Libra*. Therefore, no full moon in the year will continue to riſe ſo near the time of ſun-ſet for a week or ſo, as theſe two full moons do, which fall in the time of harveſt.

In the winter months, the moon is in *Piſces* and *Aries* about her firſt quarter; and as theſe ſigns riſe about noon in winter, the moon's riſing in them paſſes unobſerved. In the ſpring months, the moon changes in theſe ſigns, and conſequently riſes at the ſame time with the ſun; ſo that it is impoſſible to ſee her at that time. In the ſummer months ſhe is in theſe ſigns about her third quarter, and riſes not until mid-night, when her riſing is but very little taken notice of; eſpecially as ſhe is on the decreaſe. But in the harveſt months ſhe is at the full, when in theſe ſigns, and being oppoſite to the ſun, ſhe riſes when the ſun ſets (or ſoon after) and ſhines all the night.

In ſouthern latitudes, *Virgo* and *Libra* riſe at as ſmall angles with the horizon, as *Piſces* and *Aries* do in the northern; and as our ſpring is at the time of their harveſt, it is plain their harveſt full moons muſt be in *Virgo* and *Libra*; and will therefore riſe with as little difference of time, as ours do in *Piſces* and *Aries.*

For a fuller account of this matter, I muſt refer the reader to my Aſtronomy, in which it is deſcribed at large.

## PROBLEM XI.

*To explain the equation of time, or difference of time between well-regulated clocks and true ſun-dials.*

The earth's motion on its axis being perfectly equable, and thereby cauſing an apparent equable motion of the ſtarry heaven round the ſame axis, produced to the poles of the heaven; it is plain that equal portions of the celeſtial equator paſs over the meridian in equal parts of time, becauſe the axis of the world is perpendicular to the plane of the equator. And therefore, if the ſun kept his annual courſe in the celeſtial equator, he would always revolve from the meridian to the meridian again in 24 hours exactly, as ſhewn by a well-regulated clock.

But as the ſun moves in the ecliptic, which is oblique both to the plane of the equator and axis of the world, he cannot always revolve from the meridian to the meridian again in 24 equal hours; but ſometimes a little ſooner, and at other times a little later, becauſe equal portions of the ecliptic paſs over the meridian in unequal parts of time, on account of its obliquity. And this difference is the ſame in all latitudes.

To ſhew this by a globe, make chalk-marks all around the equator and ecliptic, at equal diſtances from one another (ſuppoſe 10 degrees) beginning at *Aries* or at *Libra*, where theſe two circles interſect each other. Then turn the globe round its axis, and you will ſee that all the marks in the firſt quadrant of the ecliptic, or from the beginning of *Aries* to the beginning of *Cancer*, come ſooner to the braſen meridian than their correſponding marks do on the equator; thoſe in the ſecond quadrant, or from the beginning of *Cancer* to the beginning of *Libra*, come later: thoſe in the third quadrant, from *Libra* to *Capricorn*, ſooner; and thoſe in the fourth, from *Capricorn* to *Aries*, later. But thoſe at the beginning of each quadrant come to the meridian at the ſame time with their correſponding marks on the equator.

Therefore,

Therefore, whilſt the ſun is in the firſt and third quadrants of the ecliptic, he comes ſooner to the meridian every day than he would do if he kept in the equator; and conſequently he is faſter than a well-regulated clock, which always keeps equable or equatorial time: and whilſt he is in the ſecond and fourth quadrants, he comes later to the meridian every day than he would do if he kept in the equator; and is therefore ſlower than the clock. But at the beginning of each quadrant, the ſun and clock are equal.

And thus, if the ſun moved equably in the ecliptic, he would be equal with the clock on four days of the year, which would have equal intervals of time between them. But as he moves faſter at ſome times than at others (being eight days longer in the northern half of the ecliptic than in the ſouthern) this will cauſe a ſecond inequality; which combined with the former, ariſing from the obliquity of the ecliptic to the equator, makes up that difference, which is ſhewn by the common equation tables to be between good clocks and true ſun-dials.

PLATE VIII.

Fig. 1.

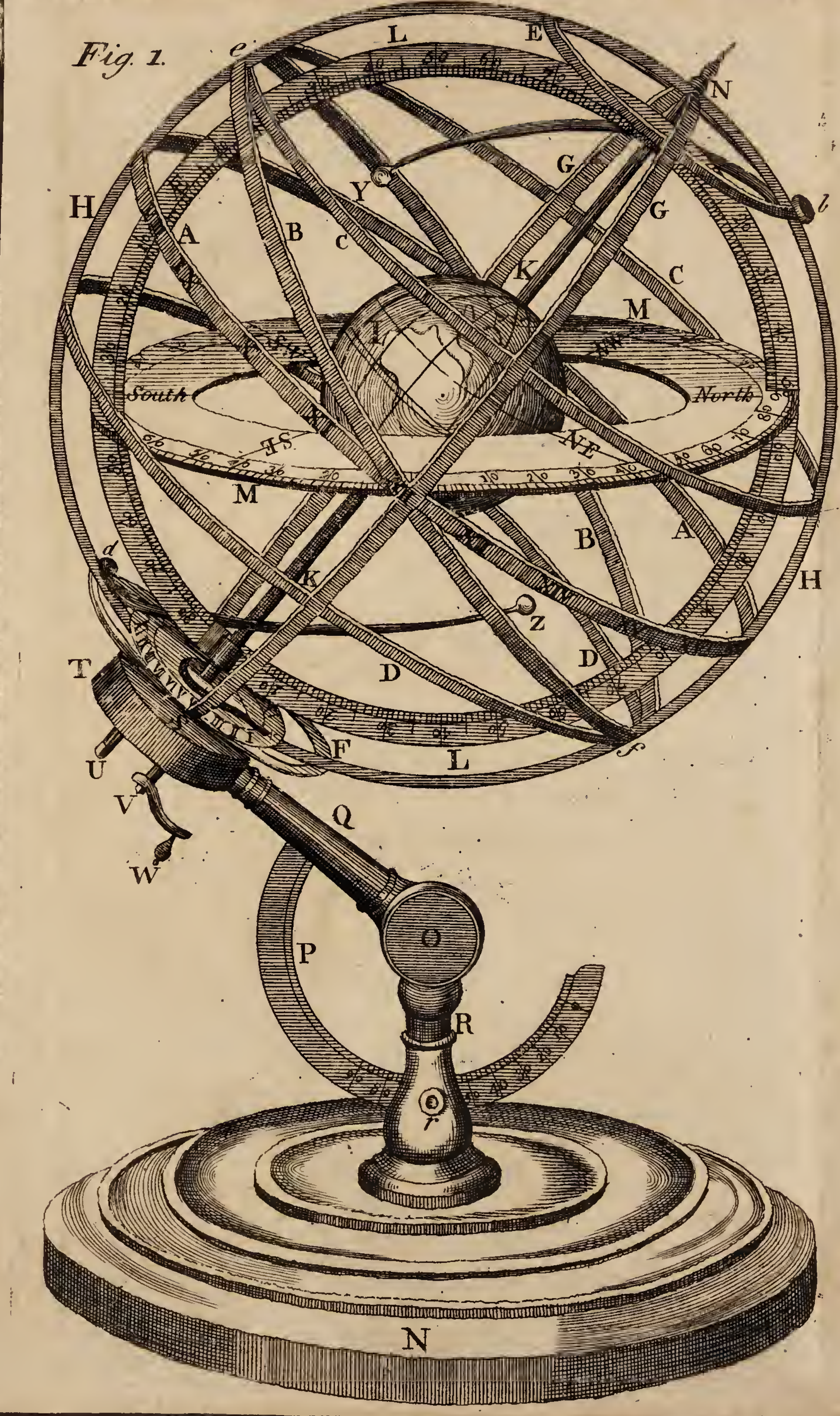


Fig. 2.

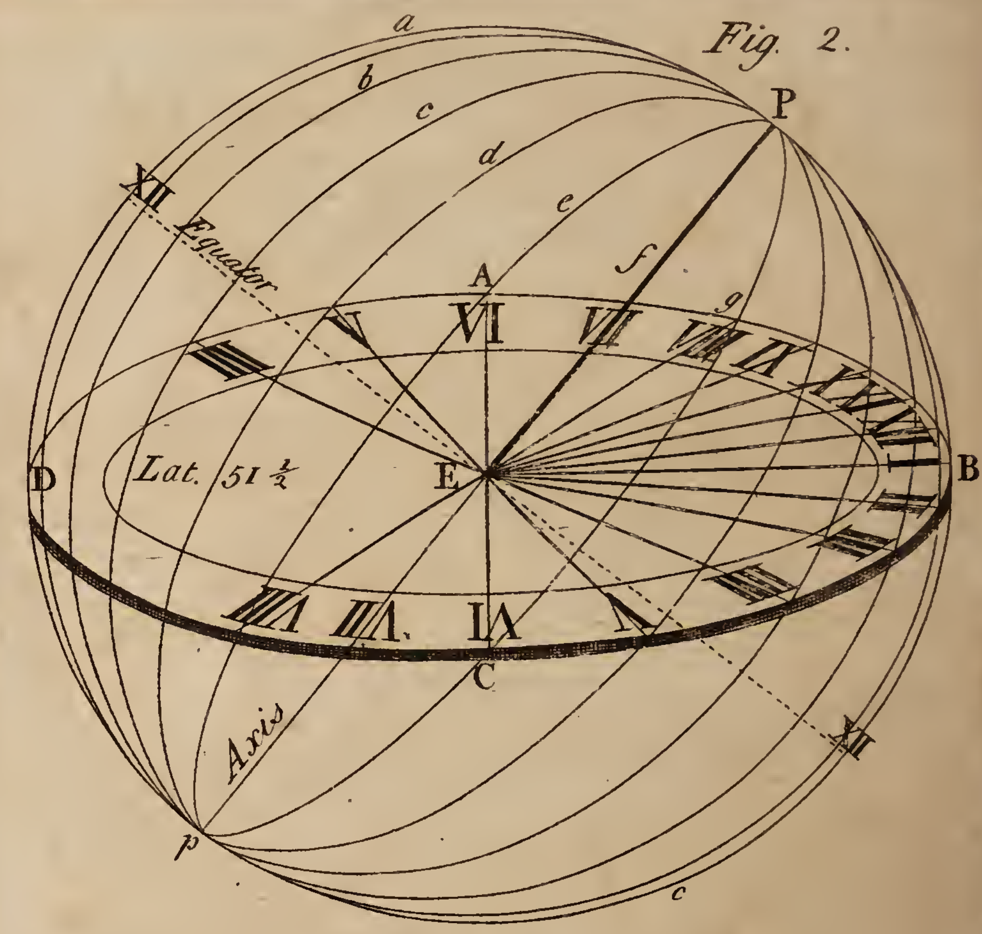
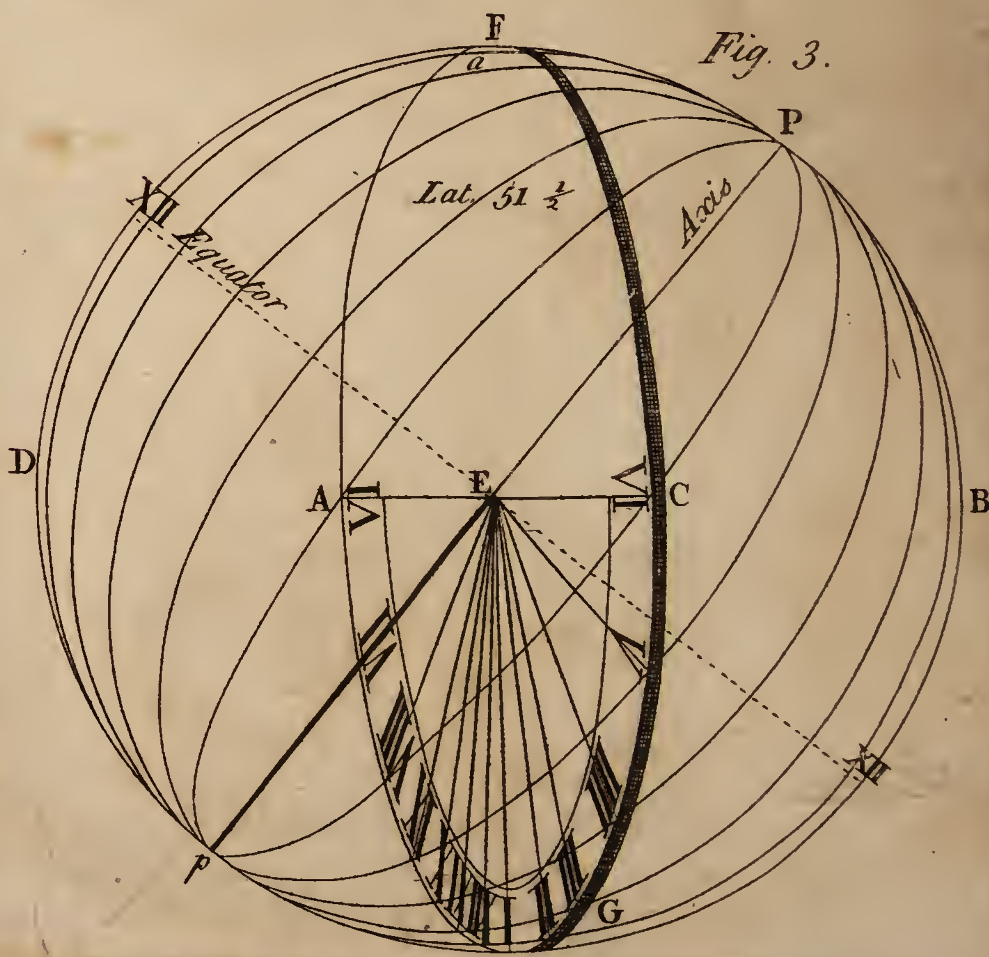


Fig. 3.



# The Deſcription and Uſe of the Armillary Sphere.

WHOEVER has ſeen a common *armillary ſphere*, and underſtands how to uſe it, muſt be ſenſible that the machine here referred to, is of a very different, and much more advantageous conſtruction. And whoever has ſeen the curious glaſs ſphere invented by Dr. LONG, or the figure of it in his Aſtronomy, muſt know that the furniture of the terreſtrial globe in this machine, the form of the pedeſtal, and the manner of turning either the earthly globe, or the circles which ſurround it, are all copied from the Doctor's glaſs ſphere; and that the only difference is, a parcel of rings inſtead of a glaſs celeſtial globe; and all the additions are a moon within the ſphere, and a ſemicircle upon the pedeſtal.

The *armillary ſphere.*

The exterior parts of this machine are a compages of braſs rings, which repreſent the principal circles of the heaven, viz. 1. The equinoctial *A A,* which is divided into 360 degrees (beginning at its interſection with the ecliptic in *Aries)* for ſhewing the ſun's right aſcenſion in degrees; and alſo into 24 hours, for ſhewing his right aſcenſion in time. 2. The ecliptic *B B,* which is divided into 12 ſigns, and each ſign into 30 degrees, and alſo into the months and days of the year; in ſuch a manner, that the degree or point of the ecliptic, in which the ſun is, on any given day, ſtands over that day in the circle of months. 3. The tropic of *Cancer C C,* touching the ecliptic at the beginning of *Cancer* in *e,* and the tropic of *Capricorn D D,* touching the ecliptic at the beginning of *Capricorn* in *f*; each 23½ degrees from the equinoctial circle. 4. The arctic circle *E,* and the antarctic circle *F,* each 23½ degrees from its reſpective pole at *N* and *S.* 5. The equinoctial colure *G G,* paſſing through the north and ſouth poles of the heaven at *N* and *S,* and through the equinoctial points *Aries* and *Libra,* in the ecliptic. 6. The ſolſtitial colure *H H,* paſſing through the poles of the heaven, and through the ſolſtitial points *Cancer* and *Capricorn,* in the ecliptic. Each quarter of the former of theſe colures is divided into 90 degrees, from the equinoctial to the poles of the world, for ſhewing the declination of the ſun, moon, and ſtars; and each quarter of the latter, from the ecliptic at *e* and *f*, to its poles *b* and *d*, for ſhewing the latitudes of the ſtars.

In the north pole of the ecliptic is a nut *b*, to which is fixed one end of a quadrantal wire, and to the other end a ſmall ſun *Y*, which is carried round the ecliptic *B B*, by turning the nut: and in the ſouth pole of the ecliptic is a pin at *d*, on which is another quadrantal wire, with a ſmall moon *Z* upon it, which may be moved round by hand: but there is a particular contrivance for cauſing the moon to move in an orbit which croſſes the ecliptic at an angle of $5\frac{1}{3}$ degrees, in two oppoſite points called the *moon's nodes*; and alſo for ſhifting theſe points backward in the ecliptic, as the *moon's nodes* ſhift in the heaven.

Within theſe circular rings is a ſmall terreſtrial globe *I*, fixt on an axis *K K*, which extends from the north and ſouth poles of the globe at *n* and *s*, to thoſe of the celeſtial ſphere at *N* and *S*. On this axis is fixt the flat celeſtial meridian *L L*, which may be ſet directly over the meridian of any place on the globe, and then turned round with the globe, ſo as to keep over the ſame meridian upon it. This flat meridian is graduated the ſame way as the braſs meridian of a common globe, and its uſe is much the ſame. To this globe is fitted the moveable horizon *M M*, ſo as to turn upon two ſtrong wires proceeding from its eaſt and weſt points to the globe, and entering the globe at oppoſite points of its equator, which is a moveable braſs ring let into the globe in a groove all around its equator. The globe may be turned by hand within this ring, ſo as to place any given meridian upon it, directly under the celeſtial meridian *L L*. The horizon is divided into 360 degrees all around its outermoſt edge, within which are the points of the compaſs, for ſhewing the amplitude of the ſun and moon, both in degrees and points. The celeſtial meridian *L L* paſſes through two notches in the north and ſouth points of the horizon, as in a common globe: but here, if the globe be turned round, the horizon and meridian turn with it. At the ſouth pole of the ſphere is a circle of 24 hours, fixt to the rings, and on the axis is an index which goes round that circle, if the globe be turned round its axis.

The whole fabrick is ſupported on a pedeſtal *N*, and may be elevated or depreſſed upon the joint *O*, to any number of degrees from 0 to 90, by means of the arc *P*, which is fixed into the ſtrong braſs arm *Q*, and ſlides in the upright piece *R*, in which is a ſcrew at *r*, to fix it at any proper elevation.

In the box *T* are two wheels (as in Dr. *Long*'s ſphere) and two pinions, whoſe axes come out at *V* and *U*; either of which may be turned by the ſmall winch *W*. When the winch is put upon the axis *V*, and turned backward, the terreſtrial globe, with its horizon and celeſtial meridian, keep at reſt; and the whole ſphere of circles turns round from eaſt, by ſouth, to weſt carrying the ſun *Y*, and moon *Z*, round the ſame way, and cauſing them to riſe above and ſet below the horizon. But when the winch is put upon the axis *U*, and turned forward, the ſphere with the ſun and moon keep at reſt; and the earth, with its horizon and meridian, turn round from weſt, by ſouth, to eaſt; and bring the ſame points of the horizon to the ſun and moon, to which theſe bodies came when the earth kept at reſt, and they were carried round it; ſhewing that they riſe and ſet in the ſame points of the horizon, and at the ſame times in the hour-circle, whether the motion be in the earth or in the heaven. If the earthly globe be turned, the hour-index goes round its hour-circle; but if the ſphere be turned, the hour-circle goes round below the index.

And ſo, by this conſtruction, the machine is equally fitted to ſhew either the real motion of the earth, or the apparent motion of the heaven.

To rectify the ſphere for uſe, firſt ſlacken the ſcrew *r* in the upright ſtem *R*, and taking hold of the arm *Q*, move it up or down until the given degree of latitude for any place be at the ſide of the ſtem *R*; and then the axis of the ſphere will be properly elevated, ſo as to ſtand parallel to the axis of the world, if the machine be ſet north and ſouth by a ſmall compaſs: this done, count the latitude from the north pole, upon the celeſtial meridian *L L*, down towards the north notch of the horizon, and ſet the horizon to that latitude; then, turn the nut *b* until the ſun *Y* comes to the given day of the year in the ecliptic, and the ſun will be at its proper place for that day: find the place of the moon's aſcending node, and alſo the place of the moon, by an Ephemeris, and ſet them right accordingly: laſtly, turn the winch *W*, until either the ſun comes to the meridian *L L*, or until the meridian comes to the ſun (according as you want the ſphere or earth to move) and ſet the hour-index to the XII, marked noon, and the whole machine will be rectified.—Then turn the winch, and obſerve when the ſun or moon riſe and ſet in the horizon, and the hour-index will ſhew the times thereof for the given day.

As thoſe who underſtand the uſe of the globes will be at no loſs to work many other problems by this ſphere, it is needleſs to enlarge any farther upon it.

◆

THE END.